DIRECT 2.0 Space Exploration Architecture Performance Analysis

Marshall Space Flight Center

Analysis Performed: October 2007
May 2007

Introduction

- Compare and contrast system-level capabilities of the DIRECT architecture with the baseline Constellation Mission architecture
  - Use same tools, analysis processes, ground-rules and assumptions

- Assessment not meant to advocate one architecture or solution
  - Multiple launch vehicle and infrastructure solutions are suitable to carry out the Constellation Program Objectives
  - Reference NASA ESAS Report

Contents

DIRECT Background

- ♦ DIRECT is a proposed architectural alternative to Constellation, submitted to the AIAA by TeamVision Corporation
- ♦ DIRECT intends to cut costs by maximizing commonality with STS
- ♦ DIRECT's alternative to the Ares V is the "Jupiter 232", which is the focus of the analysis in this document
- ♦ Current (09/19/07) DIRECT Proposal is an update of the second revision (v2.0) of the DIRECT Architecture (Original released 10/25/06)

DIRECT Launch Architecture

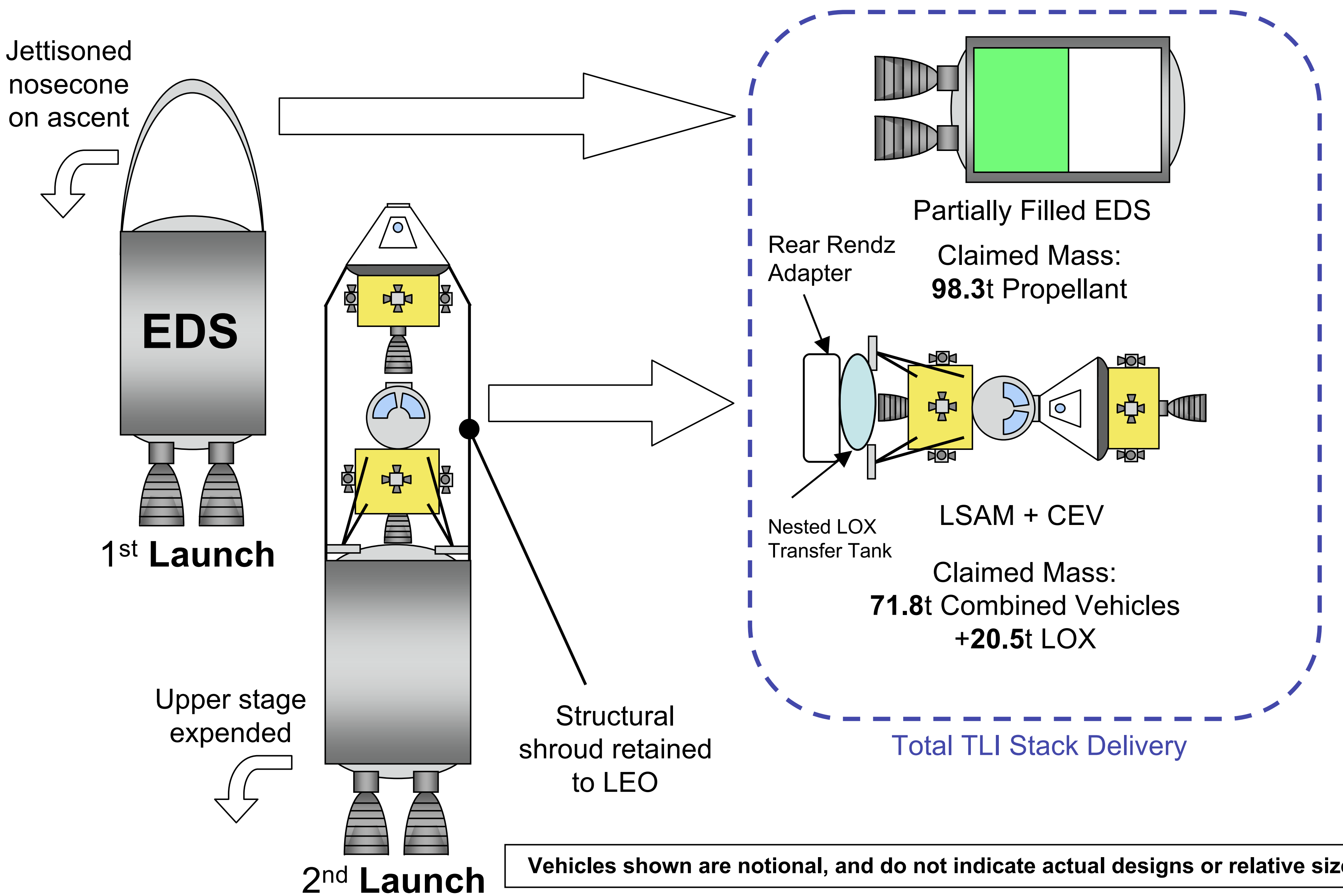
- While DIRECT v2.0 emphasizes multiple possible lunar architectures, the document outlines a Contellation-comparable EOR-LOR mission using two launches of the Jupiter 232

- The first launch is a fueled upper stage (EDS), while LSAM and CEV are launched together afterward

- LSAM and CEV dock with the EDS in LEO before TLI

Jupiter 232 Configurations
(Source: AIAA-2007-6231 fig. 96, pg. 79)

DIRECT Launch Architecture



Vehicles shown are notional, and do not indicate actual designs or relative sizes

Analysis of DIRECT Launch Architecture

- For assessing DIRECT claims, simulations are conducted first with DIRECT's stated masses, then with masses calculated to fit the descriptions
  - 1st Step Used Direct masses and removed LOX transfer to get closer to Project Constellation mission guidelines

- Constellation IDAC-3 assumptions and ground rules are used in calculations and simulations (except where otherwise noted)
  - Sized vehicle with current ground rules and assumptions
  - 222km (120nmi) circular orbit at 28.5 degrees for LEO insertion orbit

- EOR-LOR TLI Stack is used as the comparison 'common ground' where the architectures are the most similar to the Constellation architecture

Summary Conclusions

- Analysis of the DIRECT architecture shows significant performance shortfall in assessed capability
  - The DIRECT architecture aggressively estimates its stage dry mass predictions, which results in optimistic in-space performance
  - Consequently, the Direct 2.0 would likely be a 3 Vehicle Launch Solution Mission to accomplish the Project Constellation Payload Requirements with NASA design margins, ground rules and assumptions

- Assessed performance has improved from May 2007 EOR-LOR but still fails to meet minimum requirements by at least 50% of needed Lander Payload.
  - (May 2007 Performance EOR-LOR was a ~13t to 15.5t Lander / Oct 2007 Lander ~21t vs 45t reqt)

- EOR-LOR introduces autonomous cryo-propellant transfer to achieve HLR mission.
  - Complex rendezvous prop transfer technology will require additional 1-2 flight tests to prove out.
  - Direct will lose ~25% (~12.5t to ~14t) in assessed Lander by removing LOX Transfer technology
  - Would need to totally re-design an optimized Direct EDS for no LOX transfer to more accurately characterize this performance delta

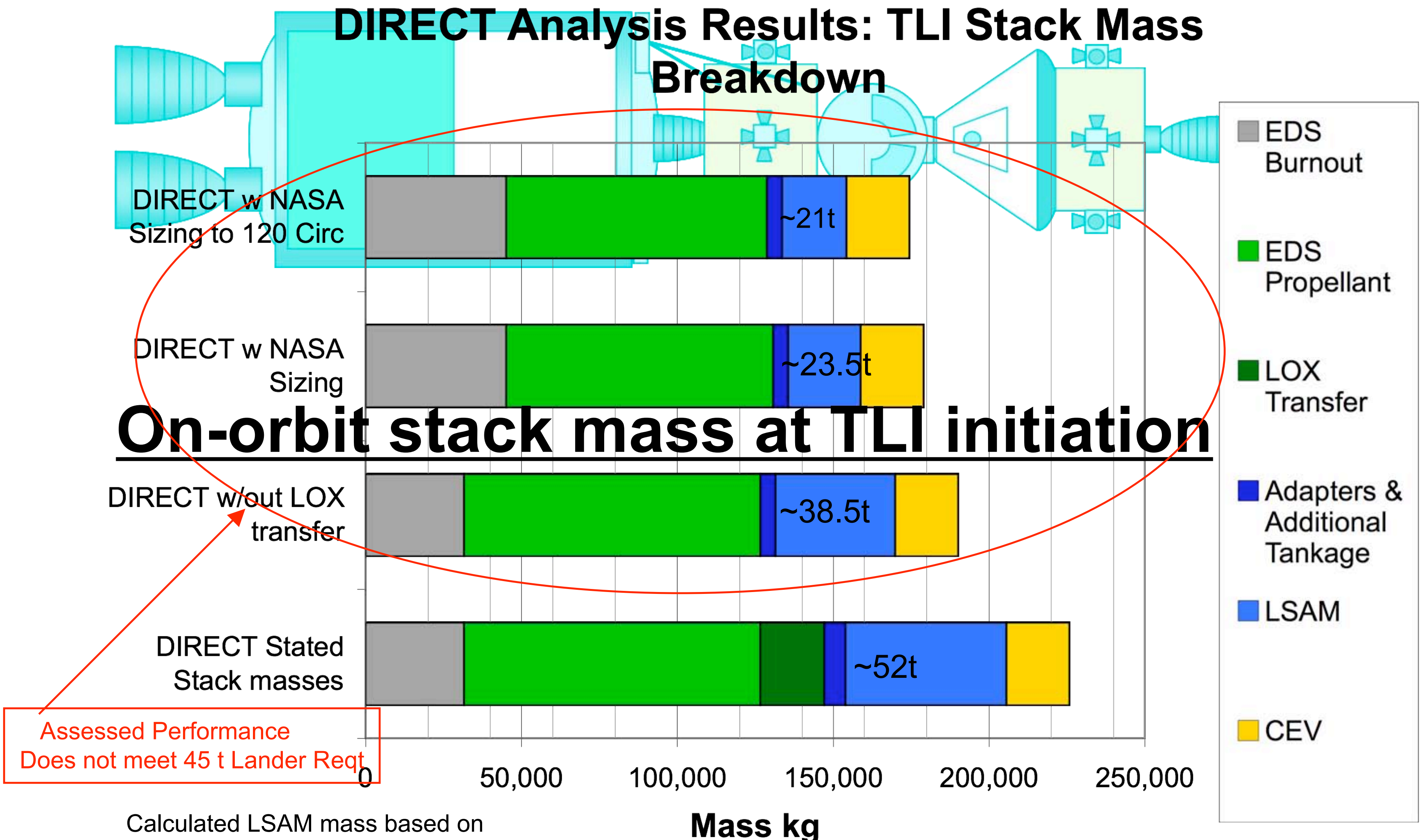
- DIRECT currently unsuitable for its proposed goal of replacing the Ares I/V architecture to carry out the earth-to-TLI transportation functions for the Constellation Programs

- DIRECT Claims to be able to close the retirement gap from Shuttle to First Flight
  - Ares I from Start-up to PDR ~3 yrs (Summer 2005 to Summer 2008)
  - Assume 6 month program restart estimate (End of 2011 for PDR, Late 2013 CDR, 2015 test flight on Jupiter 120)
  - Estimate ~1 yr delay to Orion for Delta SRR and SDR may make Orion unavailable until at least 2016.

- DIRECT cost and safety claims lack supporting data and analysis

- Ares V has evolved to optimize both earth-to-orbit and orbit-to-TLI legs of lunar mission
  - Results in significantly more lunar payload

Comparison of DIRECT & Constellation Mission



Calculated LSAM mass based on available on-orbit EDS propellant, EDS burnout mass, and fixed-mass CEV (45t Lander Reqt)

Vehicles shown are notional, and do not indicate actual designs or relative sizes

Observations of DIRECT Launch Architecture

- Manufacturing & Cost -

- **DIRECT uses (8 RSRB segment, and 2 RS68 for Crew Mission)**
  - Ares I : Uses 5 RSRB segments and 1 J2X Upperstage for Crew Mission
  - Per Mission costs for Ares I for Crew Missions are predicted to cost less than Jupiter 120 configuration.

- **DIRECT assumes that all STS manufacturing infrastructure is still in place**

- **DIRECT claims only minor redesign of ET for 232 and 120 core stages**
  - Assessment of design would lead to major redesign, development and qualification of Mod ET Core for 232 missions.
  - Predicted Touch labor of Ares 1 Upper Stage estimated to be significantly less than current ET touch labor.
  - Examined approaches like this in the past 20 years:
    - Concluded that this effort incurs significant expense and development with marginally applicable STS ET heritage:
    - the Jupiter common core requires a new : main propulsion system, thrust structure, avionics, forward LOX tank structure and a payload shroud, substantial intertank/LH2 modifications, and a stack integration effort.

- **DIRECT EDS is a 2 J2XD system with different versions to accomplish the HLR Constellation goal.**
  - Would require more on orbit loiter functionality and testing compared to Constellation Baseline
  - Cryo Prop transfer and rear rendezvous would incur significant technology development and flight testing

Observations of DIRECT Launch Architecture

- Technology Development -

- ♦ **DIRECT launch architecture proposes minimal early technology development effort for initial phase**
  - **Significant technology development initiated at lunar and Mars phases**
- ♦ **DIRECT launch architecture indicates minimal CFM technologies are needed even for 15 day loiter (maximum duration) of first of two Jupiter-232 launches (pre-position of mission propellant)**
  - **NASA Assessment of 15 day Loiter presents significant challenge to large partially filled Cryo-stage**
  - **On-orbit autonomous Cryo Prop transfer of (20.5t of LOX) requires significant enabling technology not in Constellation baseline**
- ♦ **DIRECT launch architecture does not identify minimum set of technologies and technology development plan for initial, lunar and Mars phases**
  - **No phasing plan of technologies throughout the entire program**

Observations of DIRECT Launch Architecture

- Test & Evaluation -

- DIRECT assumes minimal test requirements introduced by modifying Shuttle External Tank to Core Stage at its current size

- DIRECT does not provide a test strategy for any of the three identified launch architectures
  - No plans for propulsion, structural, IVGVT, aerodynamics, or SIL for major hardware elements and integrated vehicle for each vehicle configuration
  - No identification of test facilities required and corresponding facility modifications
  - No integration of Jupiter-232 test activities with Orion or Altair
  - No test schedule provided

Observations of DIRECT Launch Architecture
- Operations -

- DIRECT launch architecture requires increased number of spacecraft separations and dockings for all phases, increasing risk
  - Separation, flip around and docking of Orion to Altair
  - Separation of new Orion-Altair stack from second EDS
  - Rendezvous and docking of Orion-Altair stack to first EDS pre-TLI burn
  - Separation of Orion-Altair stack from first EDS post-TLI burn
- DIRECT launch architecture alternative proposes reusable Altair located at Earth-Moon Lagrange point 1 (EML1) for lunar phase
  - Additional rendezvous and docking
  - Continuous real-time operations ground support for station keeping at EML1
- DIRECT launch architecture alternative proposes propellant depot in LEO for Mars phase
  - Additional resupply and servicing missions needed to maintain depot
  - Continuous real-time operations ground support for station keeping

Observations of DIRECT Launch Architecture

- Risk Mitigation -

- ♦ DIRECT launch architecture proposes carryover of much of the STS architecture to reduce mission and crew risk

- ♦ DIRECT shows a 1/1400 PLOC for Jupiter 232 Lunar / Mission
  - No substantiating analysis presented for Direct claim
  - Ares 1 : Current PDR Estimate is 1/2400 for contribution to PLOC (after 3 years of iterated analysis)

- ♦ DIRECT Claims significant reduction in PLOM compared to Ares V

  However:
  - LOX Transfer specific contribution not addressed and would be a significant contributor to PLOM
  - Appears no On-Orbit factors addressed (14 Day Loiter plus 4 day Loiter)

- ♦ DIRECT launch architecture does not identify key risks (performance, cost or schedule) or mitigation plans
  - No links to configuration/performance enhancements or technology enhancements

Observations of DIRECT Launch Architecture
- Analysis Methodology -

♦ **DIRECT launch architecture does not include a description of analysis methodology for assessment of**

- **Overall architecture**
- **Jupiter 232 performance and safety**
- **Cost and workforce transition**
- **List of Tools with version and data validation not addressed**

Observations of DIRECT Launch Architecture
- Logistics -

- DIRECT launch architecture supports use of existing transport barge because of continuation of existing STS architecture
  - 8.4m Common Core Booster
  - 4-segment Solid Rocket Booster

- More detail on Launch Infrastructure than on vehicle design.
  - This is a design that is sized by infrastructure as they note in their paper.
  - However to date Launch infrastructure is not on the critical path of Ares V or Ares I

Issues with DIRECT - Performance

- ♦ Constellation architecture requirements have evolved since ESAS and have become more demanding

- ♦ The mass breakdowns for the Jupiter 232 shown in various places throughout the document have an approximately 2t discrepancy on claimed masses for the EDS

- ♦ Though frequently mentioned in the text of the document, DIRECT's mass breakdowns make no provision for the required 14-day loiter
  - Solar arrays, TPS, boil-off, MMOD, engine re-start
  - Lack of detail in Direct's Mass breakdown to be able to specify subsystems in sub-bullets on worksheets

Jupiter 232 Vehicle Comparison

Approximate mass of single J2XD; Second Engine not accounted for
Burnout mass goes down while Usable Propellant goes up for 2 estimates

	Figure 36	Figure 58
J-2XD	2,800	?
Burnout Mass	33,876	31,669
Propellant Usable	225,000	314,931
Mass Fraction	0.8820	0.9182

Jupiter Upper Stage Configuration:		GR&A	Margin
Number of Engines:	2		
J-2XD (May 2006):			
Isp (vac):	448		s
Oxidizer/Fuel Ratio:	6		
Maximum Thrust @ 100% (vac):	1,217,000		N
Main Propulsion System Mass:			
Total Engine:	2,800	10%	280 kg
Support Systems:	2,934	5%	147 kg
Sub-Total:	**5,734**		**kg**
Structures Mass:			
Primary Body Structures	17,490	10%	1,749 kg
Secondary Structures	1,215	15%	182 kg
Sub-Total:	**18,706**		**kg**
Ancillary Systems:			
Separation Systems:	178	10%	18 kg
TPS:	283	15%	42 kg
TCS:	1,323	15%	198 kg
Power (Electrical):	641	10%	64 kg
Power (Hydraulic):	183	10%	18 kg
Avionics:	195	15%	29 kg
Miscellaneous:	117	20%	23 kg
Sub-Total:	**2,920**		**kg**
Total Dry Mass Without Growth:	**27,360**		
GR&A Dry MassAllowance:	2,752		2,752 kg
			kg
Total Dry Mass With Growth:	**30,111**		**kg**
Residuals:		% Nominal	
Reserves:	3,181	*1.414%*	kg
Residuals:	533	*0.237%*	kg
In Flight Losses:	50	*0.022%*	kg
Sub-Total:	**3,764**	***1.673%***	**kg**
TOTAL BURNOUT MASS:	***33,876***		***kg***
Useable Propellant Mass:	225,000		kg
Engine Purge Helium Mass:	28	*(14kg/J-2XD)*	kg
TOTAL STAGE GLOW	***258,904***		***kg***
Stage pmf (full):	0.8813		
Stage pmf (minus engines - not counting TLI prop):	**0.9013**		
Jupiter Upper Stage Propellant/Tank	**9.36**	kg/kg	

COMPARISON 1:		
Ares-V Upper Stage GLOW:	247,845	kg
Ares-V Upper Engines:	3,211	kg
Aves-V Upper Plus Misc	22,078	kg
Ares-V Upper Stage Propellant (usable)	222,555	kg
Ares-V Upper Stage pmf (full):	0.8980	
Ares-V Upper Stage pmf (minus engines):	**0.9097**	
Ares-V Upper Stage kg Propellant/kg Tank	10.08	kg/kg

COMPARISON 2:		
Atlas-V Centaur Stage pmf (full):	0.9112	
Atlas-V Centaur Stage pmf (minus engines):	**0.9179**	
Atlas-V Centaur US Propellant/Tank	11.82	kg/kg

COMPARISON 3:		
Delta IV Stage pmf (full):	0.8820	
Delta IV Stage pmf (minus engines):	0.8907	
Delta IV Upper Stage (US) Propellant/Tank	8.15	kg/kg

DIRECT Jupiter Upper Stage Hardware - Exploded View

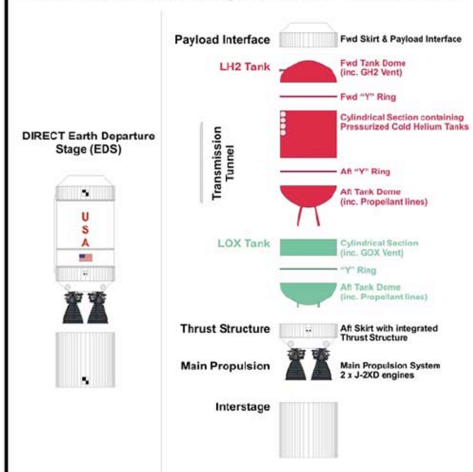
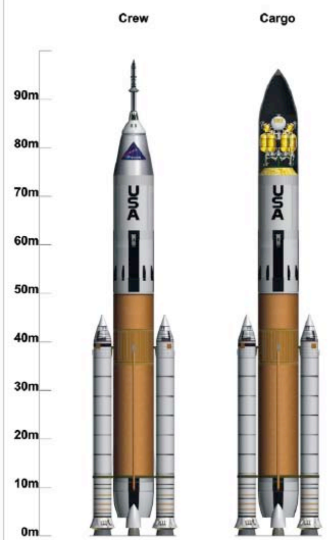


Figure 36: Jupiter Upper Stage Overall Specification and Assembly Breakout

DIRECT Jupiter-232 Launch Vehicle

Work In Progress @ 9 August 2007



Thrust/Weight @ Liftoff	1.497 : 1
Max Dynamic Pressure	523.2psf (25,053Pa)
Max g's Ascent Burn	2.18g
Insertion Altitude	120.0nm (222.2km)

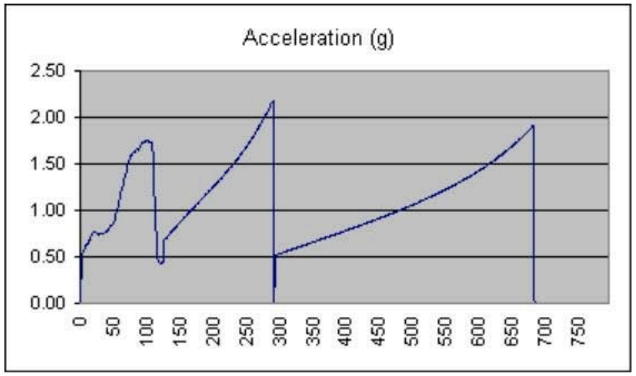
Vehicle Concept Characteristics

GLOW	**5,157,693lb (2,339,490kg)**
Payload Envelope L x D	variable x 24.5ft (7.46m)
CaLV Aero Fairing (Minimized) Mass	5,024lb (2,279kg)
CaLV Aero Fairing Jettison	T+263s
BOOSTER (each)	
Propellants	PBAN
Usable Propellant	1,105,546lb (501,567kg)
Stage pmf	0.8494
Burnout Mass	196,050lb (88,927kg)
# Boosters / Type	2 / 4-segment Shuttle RSRM
Booster Thrust (@0.7sec)	2,877,372lbf @ SL (1,305,154kgf / 12,799,188N)
	3,331,400lbf @ Vac (1,511.098kgf / 14,818,805N)
Booster Isp (@0.7sec)	237.0 s @ SL
	268.0 s @ Vac
Burn Time	123.8 s
CORE STAGE	
Propellants	LOX/LH2
Usable Propellant	1,604,970lb (728,002kg)
Propellant Offload	0.0%
Stage pmf	0.9053
Dry Mass	152,933lb (69,369kg)
Burnout Mass	167,618lb (76,030kg)
# Engines / Type	3 / RS-68 "Ablative" (man-rated)
Engine Thrust (@100%)	656,000lbf @ SL (297,557kgf / 2,919,033N)
	751,000lbf @ Vac (340,648kgf / 3,340,614N)
Engine Isp (@100%)	357.0 s @ SL
	409.0 s @ Vac
Mission Power Level	100.0%
Core Burn Time	292.0 sec
Interstage Mass	11,453lb (5,195kg)
SECOND STAGE / EDS	(This EDS Sized for EOR-LOR Architecture)
Propellants	LOX/LH2
Gross Propellant Capacity	694,304lb (314,931kg)
Usable Ascent Propellant	476,225lb (216,012kg)
Maximum Surplus Propellant Capacity	210,112lb (95,305kg)
Propellant Offload	0.0%
Stage pmf (Ascent Propellant Only)	0.8721
Dry Mass	61,850lb (28,055kg)
Burnout Mass (Excluding Payload)	69,817lb (31,669kg)
# Engines / Type	2 / J-2XD
Engine Thrust (@100%)	273,500lbf @ Vac (124,057kgf / 1,216,589N)
Engine Isp (@100%)	448.0 s @ Vac
Mission Power Level	100.0%
Ascent Burn Time	392.0 s
LEO DELIVERY ORBIT	30x120nm (55.6x222.2km) @ 28.5°
Maximum Payload (Gross)	233,458lb (105,895kg)
Maximum Payload (NET)	210,112lb (95,305kg)

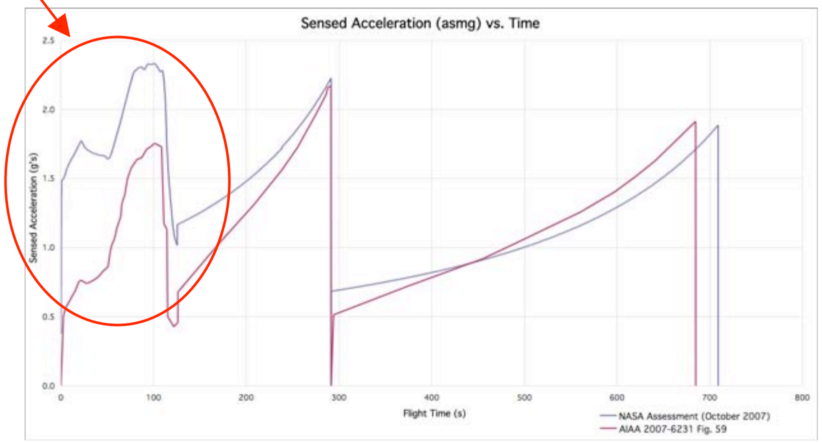
Figure 58: Jupiter-232 Specifications[41]

Issues with DIRECT – Performance

- ♦ Additional architecture compatibility is lacking supporting analysis
- ♦ Launch acceleration profile does not result in T/W greater than one until after 50 seconds into the flight
- ♦ Performance statistics are to 30nmi x 120nmi elliptical insertion orbit with circularization undefined

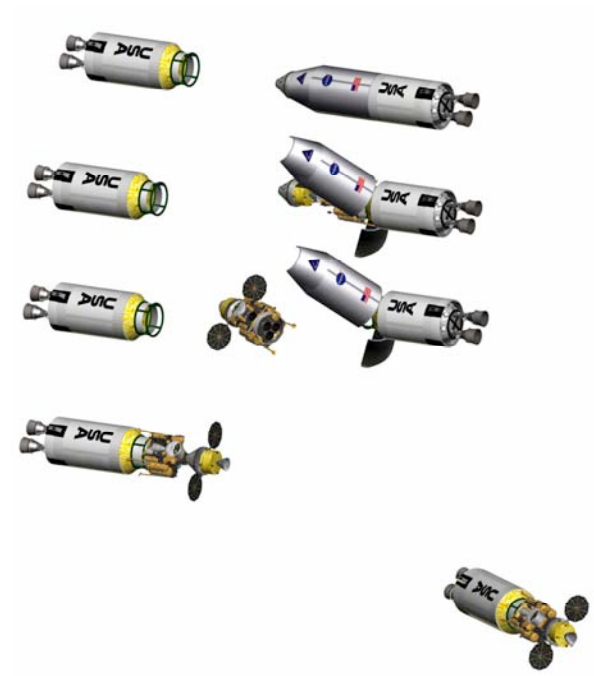


Jupiter 232 Acceleration Profile
(Source: AIAA-2007-6231, fig. 59, pg. 50)



Issues with Direct – Operations

- Increased number of dockings compared to Constellation
  - Includes 1.5 Launch Style CEV Lander EOR Docking Maneuver
  - And Includes blocked Line-of-Sight docking between CEV/LSAM and EDS with undefined docking system
  - TLI Maneuver with 2 J2XD engines will incur a ~3g or more on stack which is currently almost 2x Constellation architecture.
    - Major issue that took a year long agency study to resolve for a 1 J2X burn profile.



DIRECT EOR Rendezvous Sequence
(Source: AIAA-2007-6231, fig. 102, pg. 85)

Appendix A:
October 2007 Performance Assessment
(DIRECT v2.0 Revisited)

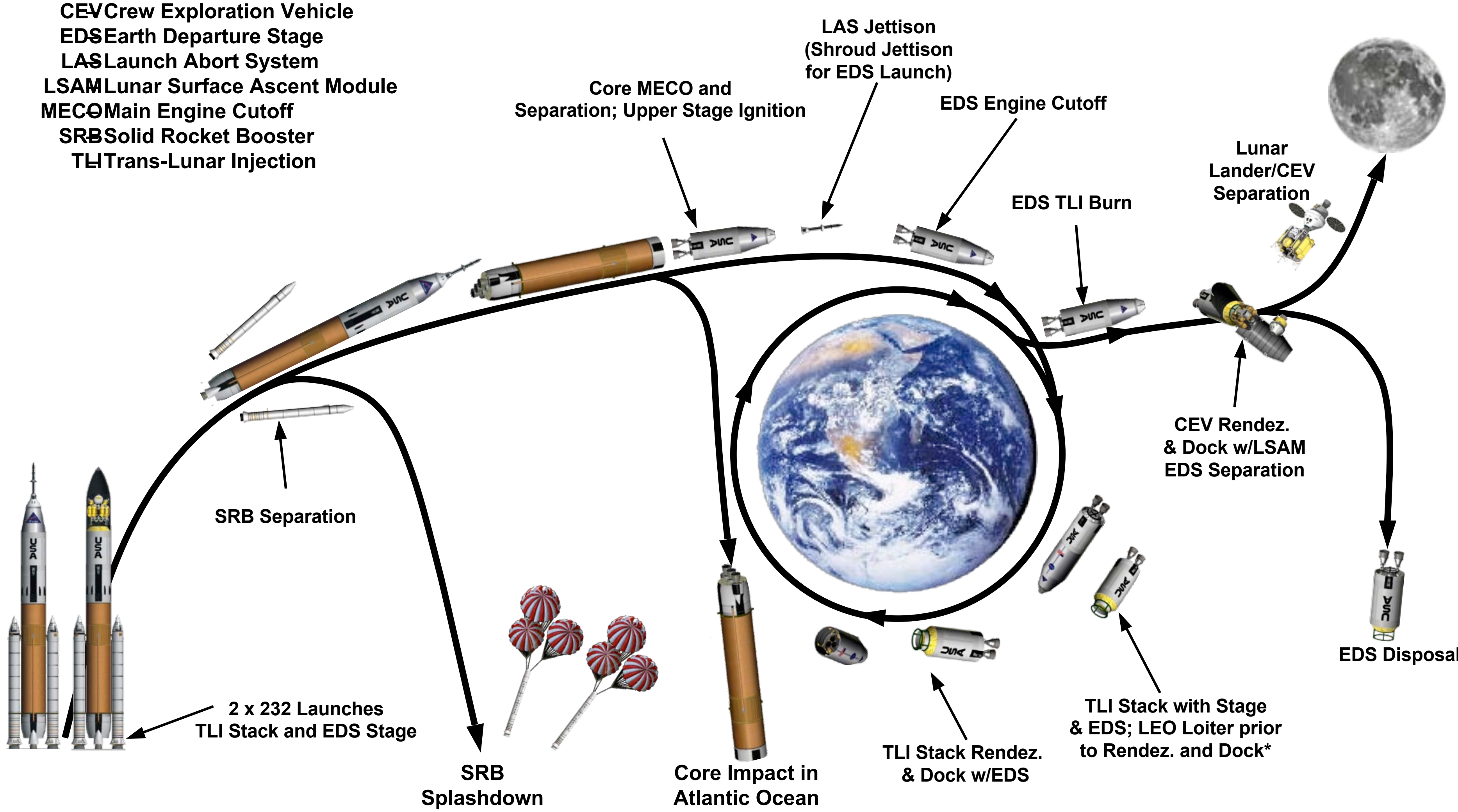
OCT 2007 Performance Assessment

- Direct 2.0 has updated their architecture and presented an AIAA Paper at Space 2007

- Noted Changes:
  - Mission for EOR-LOR now requires 2 Jupiter 232 vehicles instead of a Jupiter 120 and Jupiter 232
  - Claims 14 Day Loiter for EDS ‘Fuel’ Stage with unknown Loiter for EDS Payload Stage
  - Uses in-space Automated LOX Transfer (~20.5t) to insert ~71t of Payload to TLI (Still uses elliptical LEO Orbit and 3150m/s TLI Delta V)
  - Introduces a rear docking maneuver to execute this Transfer requiring an unknown Rendezvous Capture Adapter at Base of LSAM with LOX Tank nestled right after that
  - Has alternate SLA type mission for TLI insertion, 71t will decrease for this profile (by at least 6t SLA claimed)

EOR-LOR Mission Profile

CEV–Crew Exploration Vehicle
EDS–Earth Departure Stage
LAS–Launch Abort System
LSAM–Lunar Surface Ascent Module
MECO–Main Engine Cutoff
SRB–Solid Rocket Booster
TLI–Trans-Lunar Injection

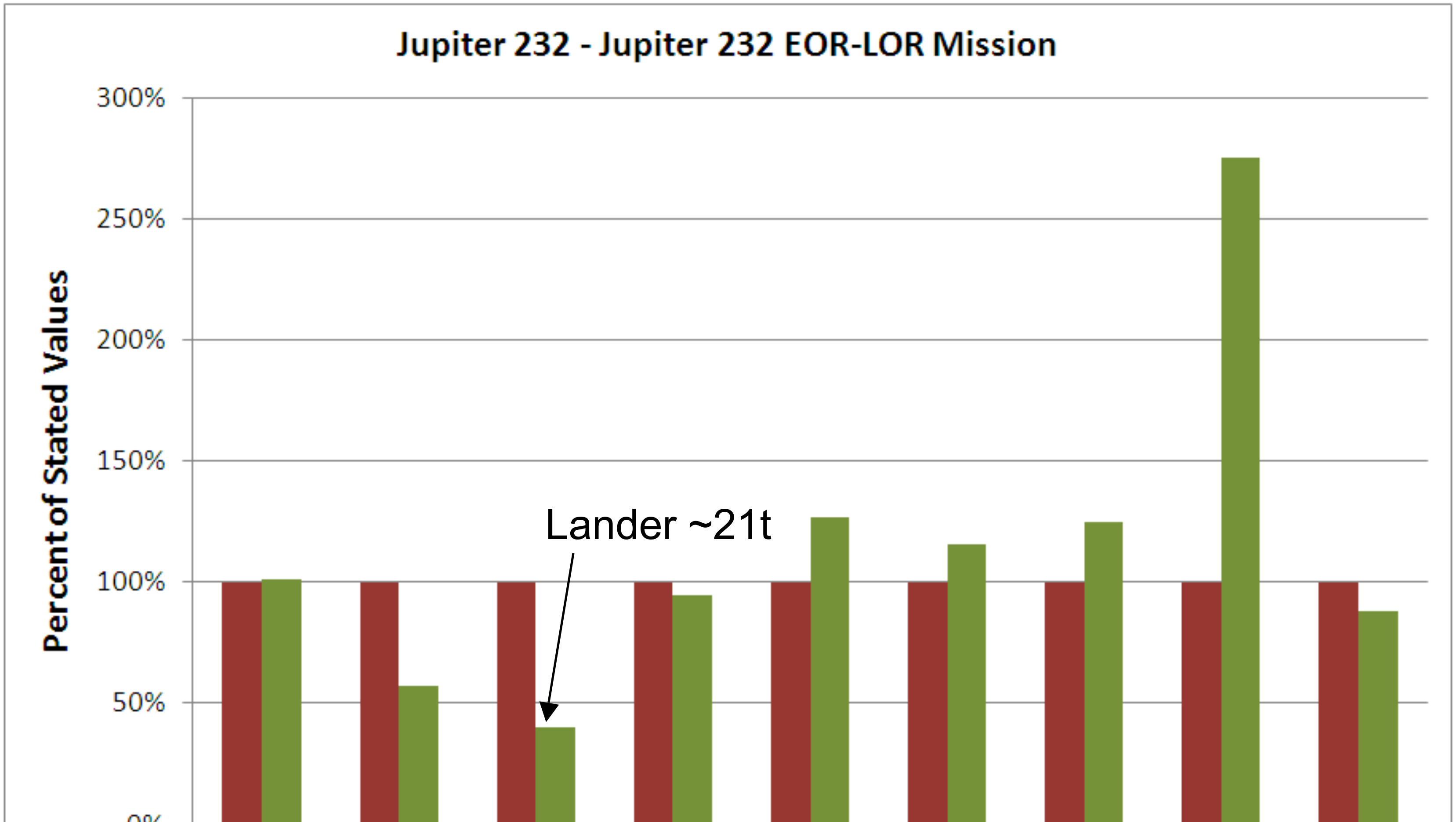


*LEO Loiter Times Vary
•Team B assumed the need for a full loiter kit
•TeamVision provides no assumptions for loiter

Ground Rules Assumptions Comparison

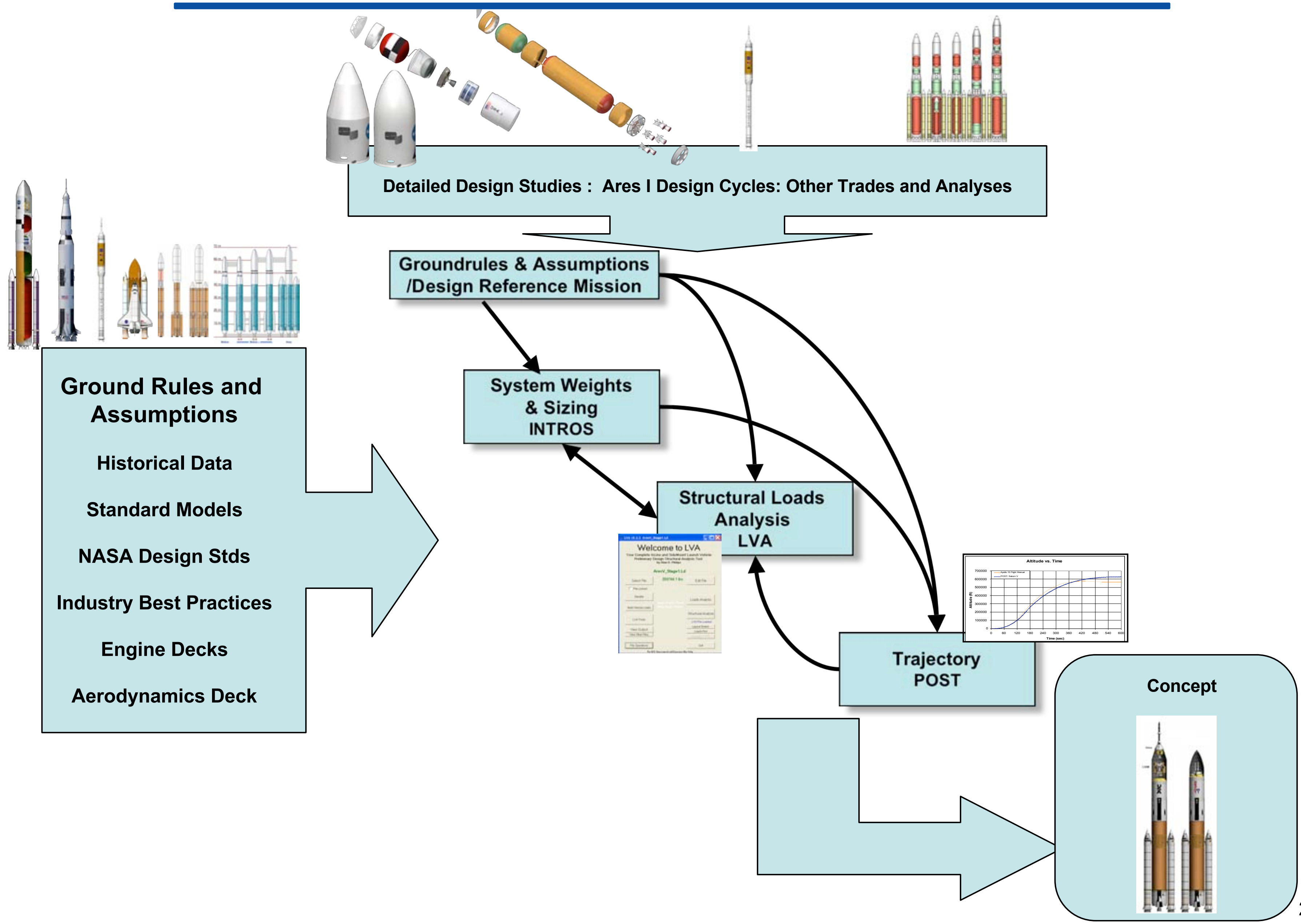
	Direct Ground Rule	NASA IDAC-3 Ares V Ground Rules
	Mass Growth Allowance	Mass Growth Allowance
	0% on Existing	0% on Existing
	5% on on Derivative elements minor mod	5% on on Derivative elements minor mod
	10% on Heritage elements	10% on Heritage elements
	15% on New Elements with Low Heritage	15% on New Elements with Low Heritage
	20% on New Elements (CEV LSAM)	Project Constellation Goal of 20% to 30% MGA on Spacecraft Concept Design
	30% Margin for Average Power	
	2% Margin for Reserves and Residuals Mass	1% FPR through TLI carried on EDS / 50% LOX Line on Core / 0.0631*Useable Prop^.8649 for EDS
	2% Ullage	3% on EDS 2% on Core
	.000246 Fuel Bias on MR	.0013 Fuel Bias Mass on (5.29 MR)
	10% Margin on Rendezvous Delta V	
	1% ascent Delta V margin for Dispersions	
	10% Payload Margin on all Payload Delivery Predictions	Goal 9t of TLI Payload Margin ~15% of Payload
	5% Additional Margin on CaLV Predictions for ASE	
		1% Thrust Degradation and 1% on Inert Wgt for SRB Knockdown Factors
	2.0 Factor of Safety for Crew Cabin	Not Sized
	1.5 Factor of Safety for Pressure Vessel (Burst)	1.4 Factor of Safety for New Designed Structures
	1.4 Ultimate Factor of Safety on all new / redesigned structure	1.4 Factor of Safety for New Designed Structures
	1.25 Factor of Safety on Proof Pressure Vessels	
		Worst on Worst Design Case Selected for Loads Analysis

October 2007 Vehicle Comparison



	GLOW	TLI Delivery	Lunar Lander	SRB Thrust	Core Dry Mass with Growth	Total Core Residuals	Upper Stage Dry Mass	Total Upper Stage Residuals	Usable TLI Propellant Mass
TeamVision	100%	100%	100%	100%	100%	100%	100%	100%	100%
Team B	101%	57%	40%	94%	126%	115%	125%	275%	88%

NASA Design Process Used for Launch Vehicle Assessment



2 x Jupiter-232 EOR-LOR Architecture Comparison

		2 x Jupiter 232 Stated Performance			2 x Jupiter 232 Assessed Performance (Team B)		
	Units	GR&A (%)	Margin Amt		GR&A (%)	Margin Amt	
GLOW (total)	kg			2,339,490			2,358,384
TLI Propellant Delivery (Launch 1)	kg	**AIAA pg. 86**		98,302			83,688
Total TLI delivery mass (Launch 2	**kg**			**71,823***** *** With LOX transfer			**40,819**
Booster Stage Specifications							
# Boosters (total)				2			2
Booster Prop (each)	kg			501,467			504,215
Booster mbo (each)	kg			88,927			84,760
Booster Thrust (vac @ <= 1sec)	N			14,823,714			13,982,286
Booster Thrust (vac @ <= 1sec)	lbf			3,331,400			3,142,302
Booster Isp (vac @ <= 1 sec)	s			268.0			269.1
Core Stage Specifications							
Number of Engines				3			3
RS-68				(existing ablative)			(existing ablative)
Isp (SL)	s			357.0			356.3
Isp (vac)	s			409.0			409.0
Maximum Thrust				(100% SL)			(100% SL)
	N			2,919,000			2,919,000
	lb_f			656,000			656,000
Maximum Thrust				(100% vac)			(100% vac)
	N			3,341,000			3,341,000
	lb_f			751,000			751,000
Main Propulsion System Mass							
Total Engine	kg	0%	0	19,800	0%	0	20,729
Support Systems	kg	5%	244	4,888	15%	1,058	7,055
Sub-Total	kg			**24,688**			**27,783**
Structures Mass							
Primary Body Structures	kg	10%	3,363	33,627	15%	6,114	40,761
Secondary Body Structures	kg	15%	186	1,237	15%	582	3,879
Sub-Total	kg			**34,864**			**44,639**

2 x Jupiter-232 EOR-LOR Architecture Comparison

		2 x Jupiter 232 Stated Performance			2 x Jupiter 232 Assessed Performance (Team B)		
	Units	GR&A (%)	Margin Amt		GR&A (%)	Margin Amt	
Ancillary Systems Mass							
Separation Systems	kg	15%	191	1,273	15%	249	1,657
TPS	kg	10%	19	187	15%	51	338
TCS	kg	10%	176	1,755	15%	346	2,307
Power (Electrical)	kg	15%	143	954	15%	188	1,251
Power (Hydraulic)	kg	15%	88	589	15%	79	528
Avionics	kg	15%	46	304	15%	32	213
Miscellaneous	kg	15%	39	260	15%	33	223
Sub-Total	kg			**5,322**			**6,519**
Total Dry Mass Without Growth	kg			**64,874**			**78,941**
GR&A Dry Mass Allowance	kg		4,494			8,732	8,732
Total Dry Mass With Growth	kg			**69,368**			**87,673**
Residuals		% Nominal					
Reserves	kg	0.760%		5,482			1,079
Residuals	kg	0.151%		1,092			7,146
In Flight Losses	kg	0.012%		87			73
Sub-Total	kg	0.923%		**6,661**			**8,298**
Total Burnout Mass	kg			**76,029**			**95,971**
Nominal Ascent Propellant	kg			721,341			728,006
Engine Purge Helium	kg	(27.3 kg/RS-68)		82			75
Total Stage Glow	kg			797,452			823,977
Stage pmf (full)				0.9114			0.8835

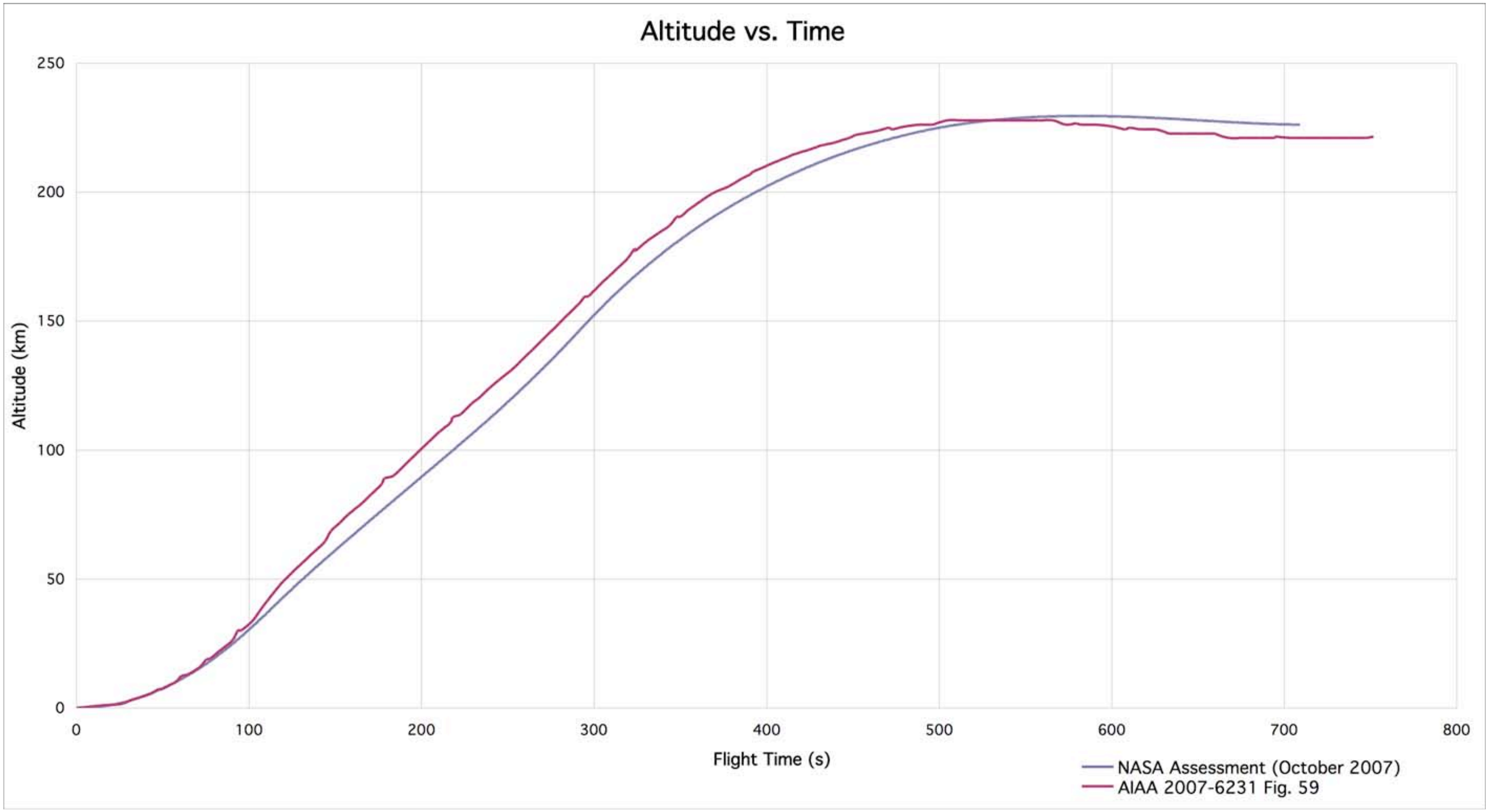
2 x Jupiter-232 EOR-LOR Architecture Comparison

	Units	2 x Jupiter 232 Stated Performance			2 x Jupiter 232 Assessed Performance (Team B)		
		GR&A (%)	Margin Amt		GR&A (%)	Margin Amt	
Upper Stage Specifications							
Number of Engines				2			2
J-2				(J-2XD; May 2006)			(J-2XD; May 2006*)
Isp (vac)	s			448			448
Oxidizer/Fuel Ratio				6			6
Maximum Thrust				(100% vac)			(100% vac)
	N			1,217,000			1,217,000
	lb_f			273,500			273,500
Main Propulsion System Mass							
Total Engine	kg	10%	280	2,800	0%	0	4,944
Support Systems	kg	5%	147	2,934	15%	350	2,336
Sub-Total	kg			**5,734**			**7,281**
Structures Mass							
Primary Body Structures	kg	10%	1,749	17,490	15%	2,639	17,592
Secondary Structures	kg	15%	182	1,215	15%	337	2,246
Sub-Total	kg		0	**18,706**		0	**19,837**
Ancillary Systems Mass							
Separation Systems	kg	10%	18	178	15%	18	121
TPS	kg	15%	42	283	15%	28	190
TCS	kg	15%	198	1,323	15%	167	1,111
Auxiliary Propulsion System	kg	N/A	N/A	N/A	15%	62	412
Power (Electrical)	kg	10%	64	641	15%	155	1,036
Power (Hydraulic)	kg	10%	18	183	15%	33	219
Avionics	kg	15%	29	195	15%	87	579
Miscellaneous	kg	20%	23	117	15%	14	93
Sub-Total	kg			**2,920**			**3,759**
Total Dry Mass Without Growth	kg			**27,360**			**30,877 ****
					**** Includes 3,337 kg for loiter structures**		
GR&A Dry Mass Allowance	kg		2,752			3,890	3,890

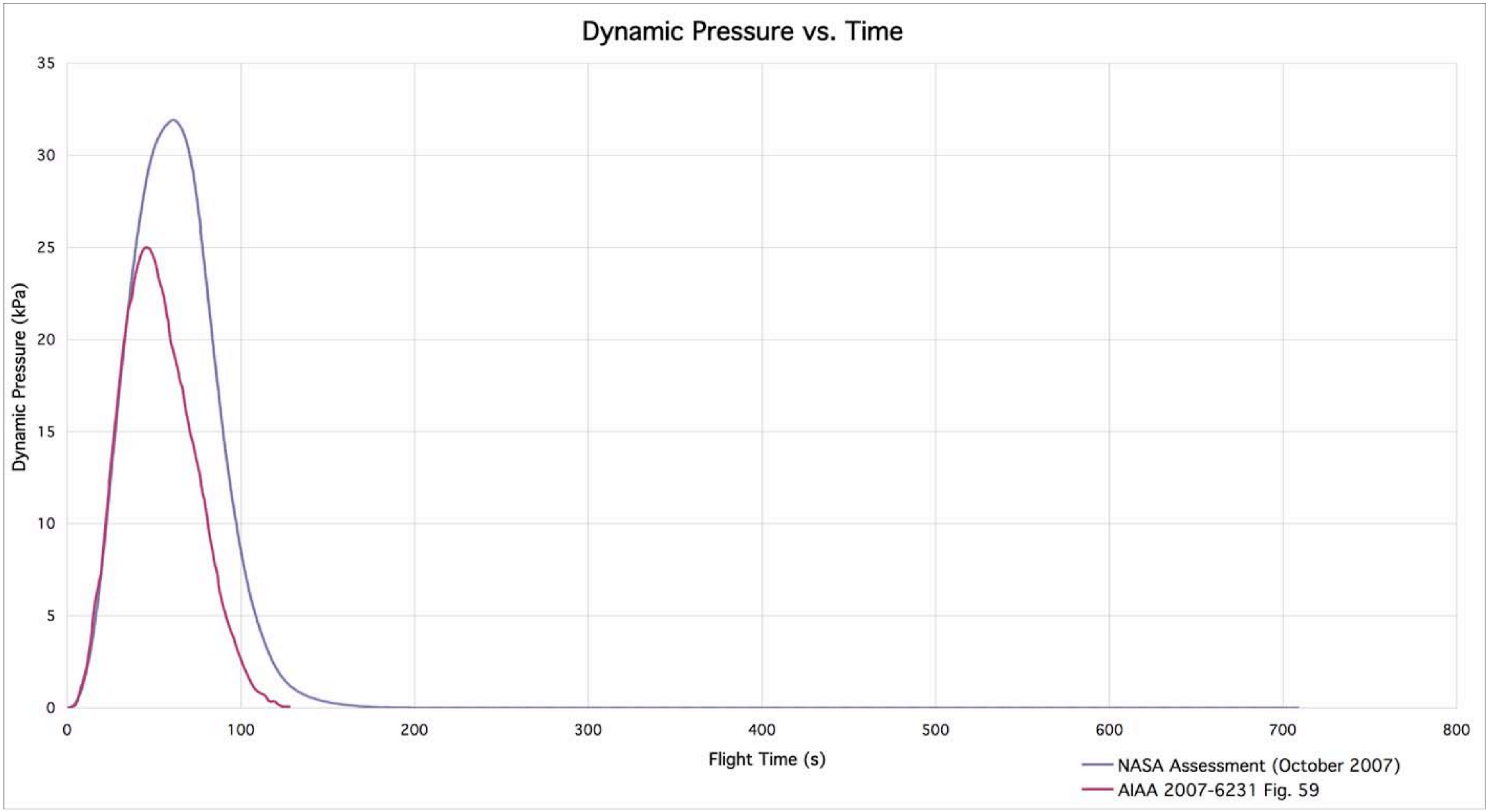
2 x Jupiter-232 EOR-LOR Architecture Comparison

		2 x Jupiter 232 Stated Performance			2 x Jupiter 232 Assessed Performance (Team B)		
	Units	GR&A (%)	Margin Amt		GR&A (%)	Margin Amt	
Total Dry Mass With Growth	kg			**30,111**			**34,767**
Residuals							
Reserves	kg			3,181			4,562
Residuals	kg			533			4,954
In Flight Losses	kg			50			844
Sub-Total	kg			**3,764**			**10,359**
Total Burnout Mass	kg			**33,876**			**45,126**
Usable Ascent Propellant Mass (sub	kg			225,000	Total propellant designed to		231,315
Usable TLI Propellant Mass	kg	Figure 58		95,305	match Gross Prop. Capacity		83,621
Engine Purge Helium Mass	kg			28			35
RCS Propellant (ascent)	N/A	N/A	N/A	N/A			939
Payload Adapter/Tank Interface	kg						2,000
Total Stage GLOW	kg			258,904			363,037
Stage pmf (full)				0.8813			0.8675

Altitude vs Time

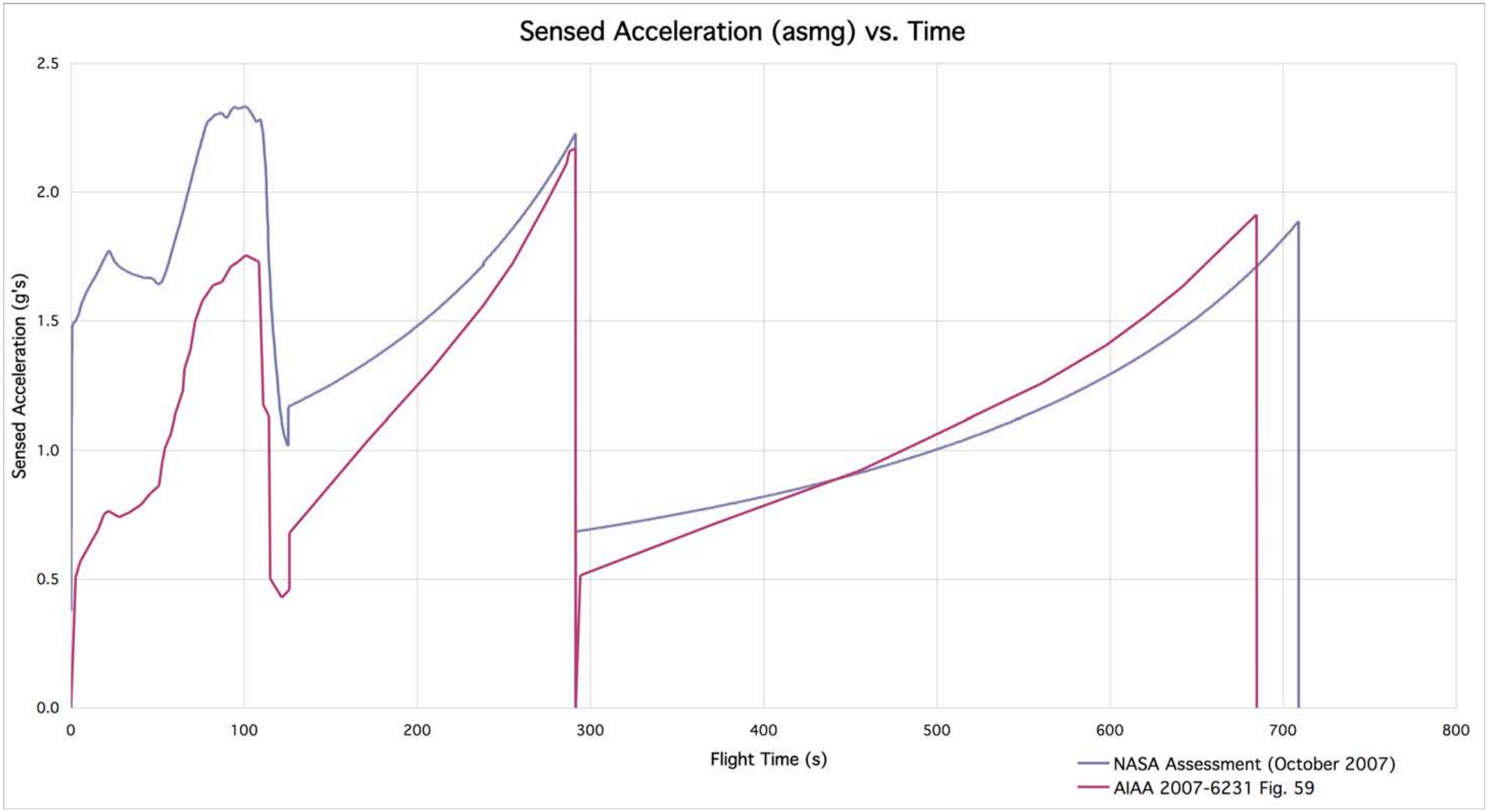


Time vs q



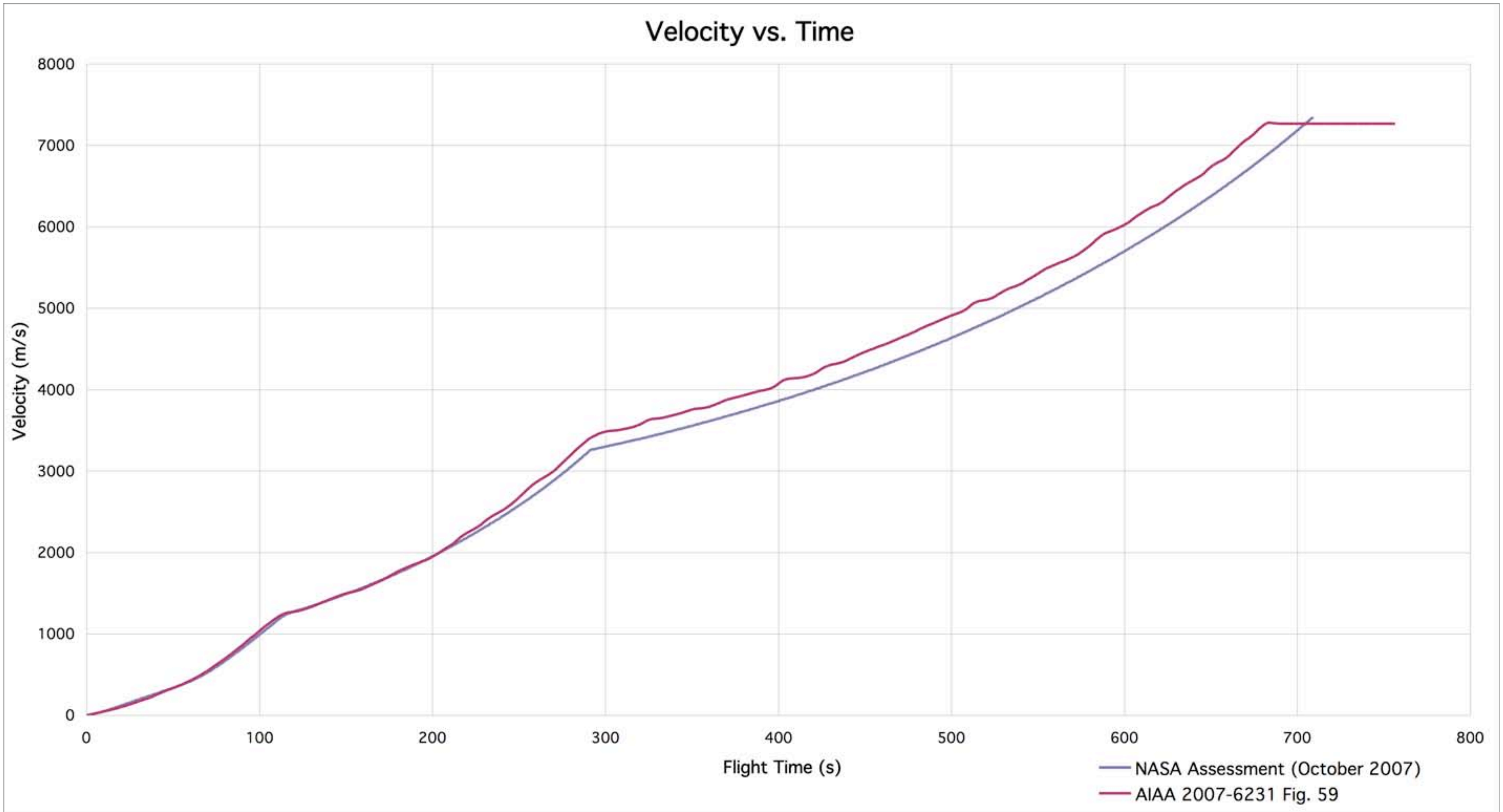
Dynamic Pressure vs. Time
Dynamic Pressure (kPa)
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
Flight Time (s)
NASA Assessment (October 2007)
AIAA 2007-6231 Fig. 59

Time vs g



Sensed Acceleration (asmg) vs. Time
Sensed Acceleration (g's)
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
Flight Time (s)
NASA Assessment (October 2007)
AIAA 2007-6231 Fig. 59

Velocity vs Time



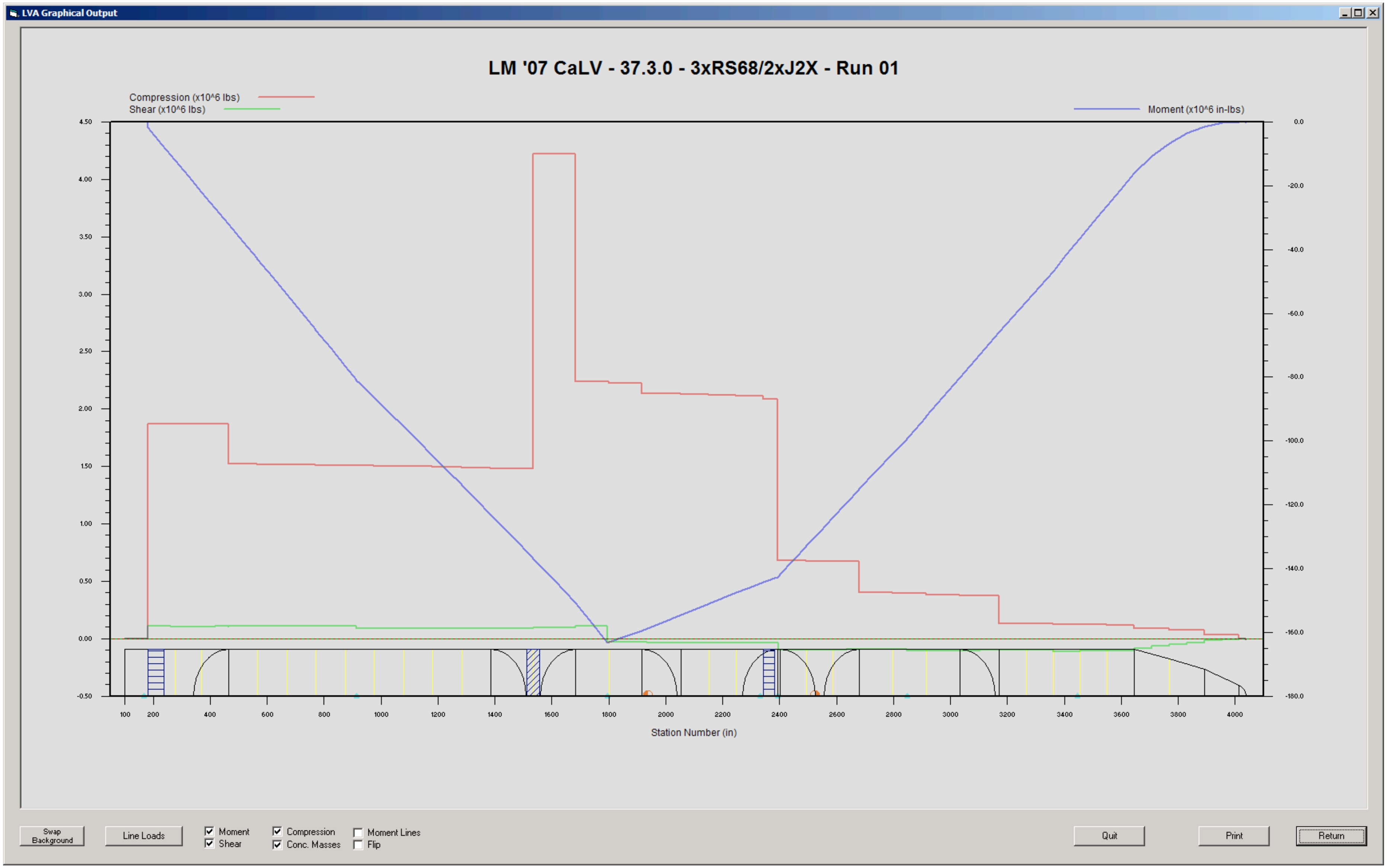
Assessment of LOX Transfer Buyback

- Question: Can the Assessed Jupiter 232 buyback needed lander mass with LOX transfer?
  - Use NASA sized 232 and perform quick assessment of max theoretical lander payload from LOX transfer
  - Assume 83.6t is Max TLI Payload from EDS ‘Fuel Stage’ Assessment
  - Assume 90% and 95% LOX transfer max capability
  - Assume 16.5t for LAS penalty, SLA, LOX Tank at 0.87 mass fraction, Adapter Docking Hardware
  - Assume a 50% (3.7t) buyback of EDS TLI Stage on-orbit Loiter systems

- Max LEO Payload Estimate w/LOX for this vehicle config: ~78t
- Max TLI Payload Est. (90% - 95%) LOX Transfer : 55t - 56t
- Equivalent Lander Payload Est. : ~35t -36t

- Still short of DIRECT Reported Lander by ~15t to 16t or >30%

Loads Assessment



Top Findings

- Direct 2.0 update uses 2 x Jupiter 232 Launches for an updated EOR LOR performance
- Assessed performance has improved from May 2007 EOR LOR but still fails to meet minimum requirements.
  - (May 2007 Performance EOR LOR was a ~13t to 15.5t Lander / Oct 2007 Lander ~21t)
- Mass statement appears to omit second J2XD engine for Upper Stage.
- Claims development cost for one vehicle but uses 2 upper-stage configs to accomplish HLR objective.
  - Shows a graphic that indicates two different sized EDS tanks for 232 Vehicles (Should name them 232a and 232b Stage Development Design and Qual testing would increase as a result)
- EOR-LOR introduces additional rear facing rendezvous docking maneuver for HLR missions.
  - This maneuver alone needs its own test flight program
- EOR-LOR introduces autonomous cryo-propellant transfer to achieve HLR mission.
  - Direct will lose ~25% (~12.5 to ~14t) in assessed Lander by removing LOX Transfer technology
  - Would need to totally re-design an optimized Direct EDS for no LOX transfer to more accurately characterize this performance delta
- Assessed dry mass of stages increased ~20% or more
- Assessed reserves and residuals increased ~20% (Core) to 275% (EDS)
  - Still appears to not have a lot of consideration for the On-orbit systems for Loiter
  - Restart propellant does not appear to be accounted for

Appendix B:
May 2007 Assessment
(DIRECT v2.0)

Mission Profile (May 2007)

- **Team A - Goal was to fly Direct LOR-LOR Mission**
  - Using 2 Launches of the 232 Config (Noted from April 2007 Summary Presentation)
  - Direct TLI Insertion C3 -1.8 km^2/s^2, EDS does LOI (~4134 fps Delta V)
  - RS-68 was 106% with 405.9 ISP (Public Available Parameter)
  - Used IDAC-3 Groundrules and Assumptions (Including J2-X Engine Parameters)

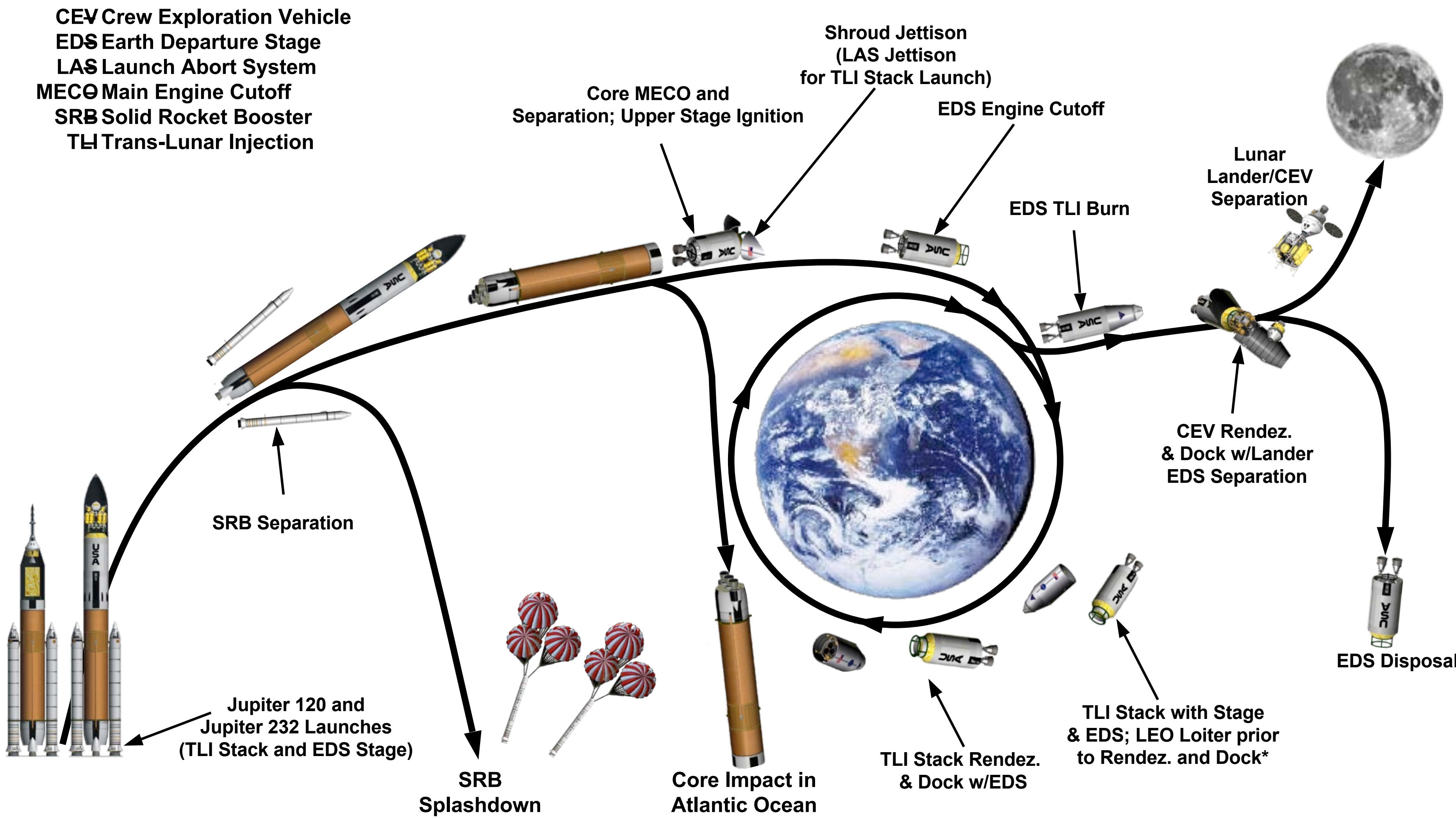
- **Team B - Goal was to fly Direct LOR LOR Mission**
  - Using 2 Launches of the 232 Config (Noted from April 2007 Summary)
  - Elliptical 30x120 then TLI maneuver as suggested by (April 2007 Summary)
  - Used Direct Claimed Engine Parameters from (April 2007 Summary Presentation)
  - Used IDAC-3 Groundrules and Assumptions

Mission Profile (May 2007)

- **Team A - Goal #2 was to fly Direct EOR (April 2007)**
  - **Assumed Jupiter 120 delivered 20.2t CEV to EOR rendezvous**
  - **Used single 232 Config (Noted from April 2007 Summary)**
  - **RS-68 was 102% with 409 ISP (Public Available Parameter)**
  - **Full Loiter kit**
  - **Flew to 120nmi Circ, Used IDAC-3 Groundrules and Assumptions**

- **Team B - Goal #2 was to fly Direct EOR (April 2007)**
  - **Assumed Jupiter 120 delivered 25t CEV as Claimed by Direct**
  - **Used single 232 Config (Noted from April 2007 Summary)**
  - **Used Direct Claimed Engine Parameters from (April 2007 Summary)**
  - **Flew to 120nmi Circ, Used IDAC-3 Groundrules and Assumptions**

EOR-LOR Mission Profile

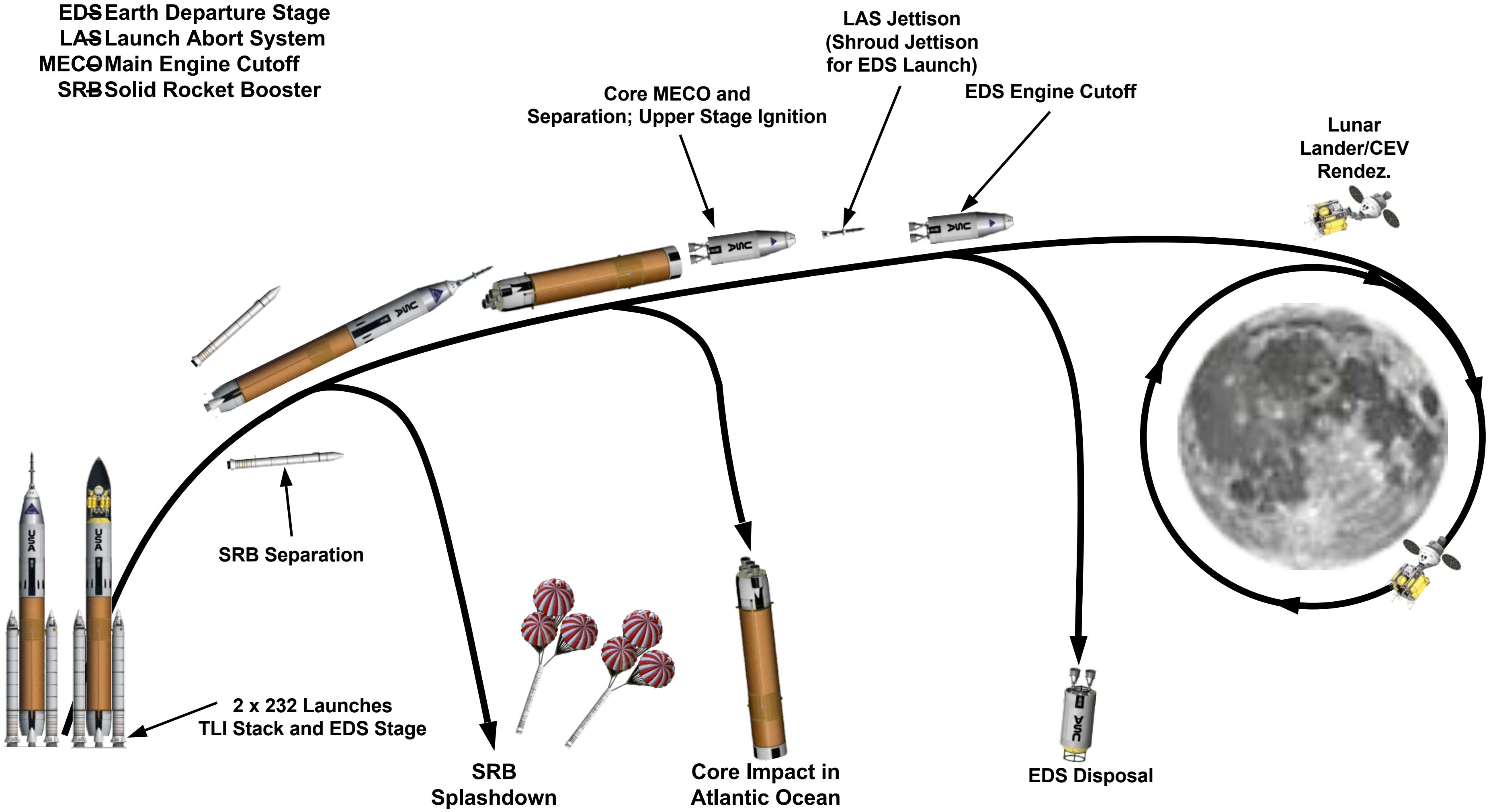


*LEO Loiter Times Vary

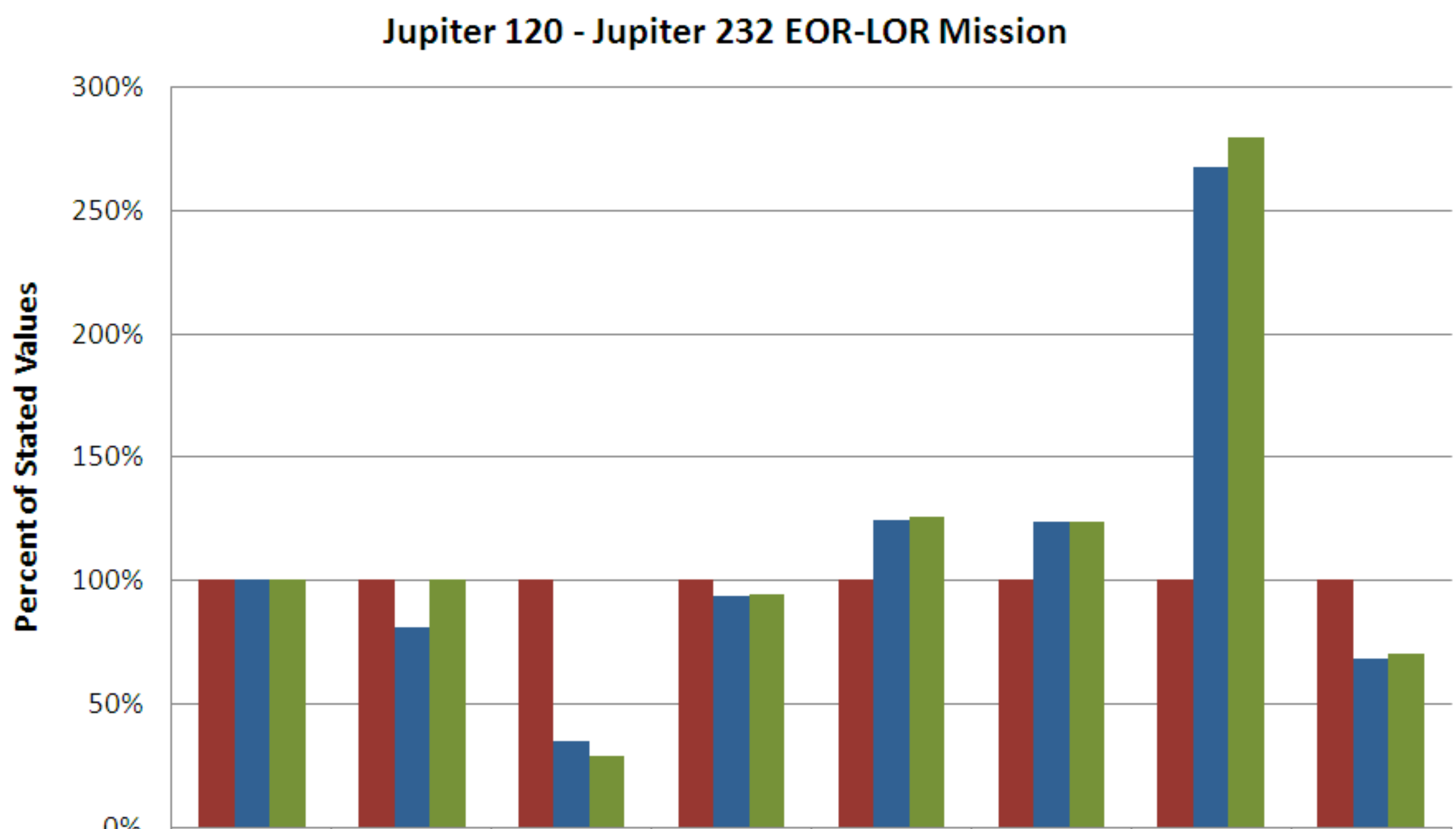
•TeamVision provides no assumptions for loiter

LOR-LOR Mission Profile

CEV – Crew Exploration Vehicle
EDS – Earth Departure Stage
LAS – Launch Abort System
MECO – Main Engine Cutoff
SRB – Solid Rocket Booster

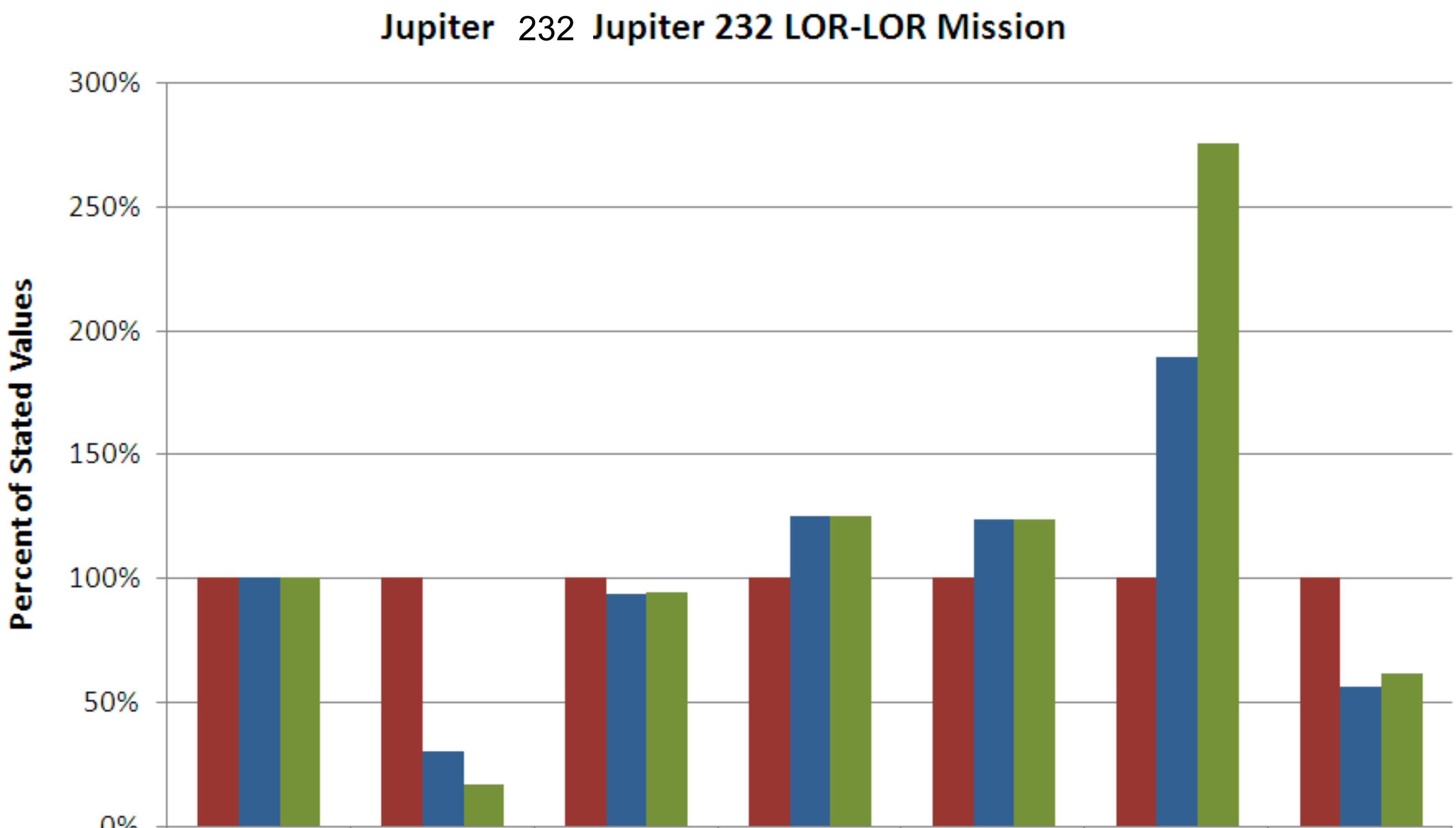


May 2007 Vehicle Comparison



	GLOW	CEV	Lander	SRB Thrust	Core Dry Mass with Growth	Total Core Residuals	Total Upper Stage Residuals	Usable TLI Propellant Mass
TeamVision	100%	100%	100%	100%	100%	100%	100%	100%
Team A	100%	81%	35%	94%	124%	123%	267%	68%
Team B	100%	100%	29%	94%	126%	123%	279%	70%

May 2007 Vehicle Comparison



	GLOW	Lander	SRB Thrust	Core Dry Mass with Growth	Total Core Residuals	Total Upper Stage Residuals	Usable TLI Propellant Mass
TeamVision	100%	100%	100%	100%	100%	100%	100%
Team A	100%	30%	94%	125%	124%	189%	56%
Team B	100%	17%	94%	125%	123%	275%	61%

Ground Rules & Assumptions

- **General GR&A**
  - Configuration
    - VAB Launch Vehicle Stack Integrated Height Constraint = 400 ft (potential trade CEV LAS integration at pad).
    - All Vehicle Stages: Diameter Constraint = up to 33 ft.
  - Payload Definitions
    - Payload is defined as the total injected mass at the end of TLI or LOI (depending on concept) minus the burnout mass of the final stage.
    - Launch vehicle payload includes the CEV (CM/SM), LSAM, payload to the lunar surface, LSAM adapter, and airborne support
    - equipment (ASE).
  - Payload Margin
    - Quoted Launch vehicle payload capabilities are 'gross' delivered to final destination (TLI *or* LOI), with *margin philosophy to be determined by ELO with concurrence of Constellation Level 2, consistent with policy documented Constellation Level II Margin Management Plan*.
- **Trajectory / Ascent Flight Profile**
  - General Trajectory GR&A
    - Baseline Trajectory Model will be generated through POST
    - Max acceleration = not to exceed 5.0 g's.
    - Max dynamic pressure = structures designed to accommodate.
    - Max Q-alpha & Q-beta = not to exceed ±5000 psf-deg
    - 3-DoF point mass
    - Launch from Pad 39A: gdlat = 28.6084 deg, long=279.3959 deg, gdalt = 0 ft
    - Standard oblate earth model (WGS-84)
    - 1963 Patrick AFB atmosphere model
    - KSC mean annual winds (P. 17-19 VIPA-SDV-SM-TR4)
    - Start simulation at lift-off (all liquid) or SRB ignition (if using solids)
    - Begin pitch-over at tower clearance (350 ft altitude).
    - Pitch over ends and gravity turn begins when Q = 150 psf.
    - alpha and sideslip angles are set to 0 during gravity turn.
    - Gravity turn ends when Q = 100 psf.
    - Optimized pitch profile after gravity turn
    - Avoid instantaneous changes in vehicle attitude
    - Serial burn staging events are instantaneous unless a coast phase is required for specific analytical purposes.
    - SRB apogee is unconstrained (product of analysis)
    - SRB separation time to be optimized for payload performance

Ground Rules & Assumptions

- **Orbital Injection into LEO**
  - Perigee and apogee are relative to a spherical earth whose radius equals earth's mean equatorial radius.
  - MECO altitude is optimized, but must be ≥ 57 nmi
  - For 1.5 Launch Scenario / Combined EDS (J2X) – Inject into 120 nmi circular orbit at 28.5 deg inclination. For purpose of initial analysis, assume 14 day loiter for CEV rendezvous and orbital decay to 100 nmi circular orbit prior to TLI burn.
- **Lunar and C3 Trajectories**
  - Perigee and apogee are relative to a spherical earth whose radius equals earth's mean equatorial radius.
  - Single Launch Lunar Direct:
  - TLI termination for Luna at apogee corresponds to C3 = -1.8 km^2/s^2.
  - CARD TLI dV:
  - TLI dV from 160 nmi circ = 3,150 m/s (for J2X Thrust class)
  - TLI dV from 100 nmi circ = 3,175 m/s (for J2X Thrust class) 3,150 m/s + 25 m/s for 60 nmi lower orbit
  - CARD LOI dV:
  - LOI dV from TLI = 1,260 m/s (assumes 3 Burn LOI and 3 Day LLO for Global Access)
- **LSAM Fairing Volume Requirements**
  - LSAM cylindrical section required length, if LSAM does LOI = 39 ft. (10m LSAM + 2m for adapter)
  - LSAM cylindrical section minimum required diameter = 27.5 ft.
- **Payload fairings**
  - Fairing structural weight determined by structural analysis
  - Fairing jettison weight includes: structures, TPS and acoustic/thermal blankets
  - Fairing jettisoned when 3-sigma Free Molecular Heating Rate = 0.1 BTU/ft^2-sec
    - 3-σ FMHR = (1/2 ρ V3) (K-factor) = (dynp) (vela) (K-factor) (conv)
    - dynp = dynamic pressure; vela = atmospheric relative velocity
    - K-factor = 2.0 (atmospheric density doubled to account for dispersions)
    - conv = 0.00128593 BTU/ft-lb units conversion factor
- **Launch Abort System (LAS) and Boost Protect Cover (BPC)**
  - LAS mass = 13065 lbm. (ratioed from 12345*14000/13228)
  - BPC mass = 935 lbm. (ratioed from 883*14000/13228)
  - LAS+BPC mass = 14000 lbm.
  - LAS+BPC jettison at 30 seconds after RSRB jettison.
  - LAS+CM+SM+LSAM adapter length = 64ft + 33ft for 10m LSAM; 64ft + 20ft for 6m LSAM
- **Ares V Aerodynamics**
  - 3-DOF aero and base force (based on Magnum wind tunnel data)

Ground Rules & Assumptions

- **Weights & Sizing (INTROS)**
  - **General W&S GR&A**
    - Dry mass margins:
      - 0% for existing hardware with no modifications
      - 5% for existing hardware with minor modifications
      - 10% for existing hardware with moderate modifications
      - 15% for new hardware and for LVA provided structural weights
    - Propellant density:
      - LOX: 71.14 lbm/ft^3
      - LH2: 4.414 lbm/ft^3
      - RP: 50.50 lbm/ft^3
    - Ullage fraction:
      - Ullage fraction is defined as the fraction of ideal tank volume that is unusable.
      - For EDS concepts: 0.03 (includes volume of slosh baffles, pressurant, anti-vortex, etc.)
      - For other stages larger than EDS (i.e. Core): 0.02 (includes volume of slosh baffles, pressurant, anti-vortex, etc.)
    - Miscellaneous Secondary Structures calculated as 5% of LVA Primary Structures
    - Vehicle sizing is considered closed when the payload capability is between the target payload and the target payload plus 0.1%.
  - **Propellant Allocation:**
    - FPR:
      - FPR is 1% of ideal dV for the mission through TLI or LOI.
      - Final stage (EDS) carries the entire FPR.
      - Any excess FPR is not calculated as payload.
    - Fuel bias:
      - Fuel bias mass (lbm) = 0.0013 * mixture ratio / 5.29 * usable propellant (based on INTROS mass estimating relationship)
      - Applies to LH2 core and upper stage(s).
    - Residuals:
      - Core Stage: Residual values based on EV MPS analysis (50% remaining in LOX feed lines)
      - EDS/Other Stages (excluding Core) residuals mass (lbm) = 0.0631 * (usable propellant)^0.8469 (based on INTROS mass estimating relationship)
    - Start propellant:
      - Core Stage based on RS-68 startup transients
      - Air Start Stages: zero start propellant allocated

Ground Rules & Assumptions

- **<u>Structures (LVA)</u>**
  - **General Structural GR&A**
    - Launch vehicle safety factors for new stages = 1.4 (consistent with NASA-STD-5001)
    - 3 sigma dispersion estimation on flight loads
    - Design max acceleration = as flown in Trajectory (POST) plus 0.1 g.
    - Design max dynamic pressure = as flown in Trajectory (POST) plus 10 psf.
    - For propellant tanks, use 50 psia MDP and a relief pressure on flight loads of 25 psia (no safety factor on relief pressure)
  - **Material Properties Assumptions:**
    - Aluminum 2219: Consistent with EV30 assumptions
    - AL-Li 2195: Consistent with EV30 assumptions
    - Composites: IM7/8552
- **<u>Engine Data</u>**
  - **Solid Rocket Booster Data for <u>Baseline</u> Cases**
    - 5 segment PBAN SRB for Ares V: 166-06 reference trace from ATK Thiokol (RSRMV16606TRDG.DAT)
    - Includes 1% thrust degradation (due to flight experience) and 1% mass contingency on inert mass
  - **RS-68 option A (RS68-optA) (all data are proprietary)**
  - **J2X:**
    - No throttle capability.
    - 100%: Thrust (vac) = 294,000 lbf, Isp (vac) = 448.0 sec (guaranteed minimum nominal) Ae = 78.54 ft^2
    - Uninstalled engine mass = 5,400 lbm, engine length = 185.0 in

2 x Jupiter 232 Architecture Comparison

- Case #1: LOR-LOR -

Direct v2.0							
		2 x Jupiter 232 Stated Performance		2 x Jupiter 232 Assessed Performance (Team A)		2 x Jupiter 232 Assessed Performance (Team B)	
	Units	GR&A (%)		GR&A (%)		GR&A (%)	
GLOW (total)	kg		2,371,593		2,372,939		2,371,124
CEV Rendezvous Mass	kg		25,000		0		0
Lander Mass (+ adapter, etc.)	kg		50,000 - 75,000		14,921		8,300
Total TLI delivery mass	**kg**		**75,000 - 100,000**		**14,921**		**8,300**
Booster Stage Specifications							
# Boosters (total)			2		2		2
Booster Prop (each)	kg		501,467		504,215		504,230
Booster mbo (each)	kg		87,604		84,760		85,250
Booster Thrust (vac @ <= 1sec)	N		14,823,714		13,865,130		13,982,585
Booster Thrust (vac @ <= 1sec)	lbf		3,331,400		3,117,005		3,142,302
Booster Isp (vac @ <= 1 sec)	s		268.0		266.9		269.1
Core Stage Specifications							
Number of Engines			3		3		3
RS-68			(existing ablative)		(ablative)		(ablative)
Isp (SL)	s		357.0		353.6		356.7
Isp (vac)	s		409.0		405.9		409.5
Maximum Thrust			(100% SL)		(106% SL)		(100% SL)
	N		2,919,000		3,064,825		2,867,000
	lb_f		656,000		689,000		644,300
Maximum Thrust			(100% vac)		(106% Vac)		(100% vac)
	N		3,341,000		3,487,406		3,292,000
	lb_f		751,000		784,000		740,000
Main Propulsion System Mass							
Total Engine	kg	0%	?	0%	20,729	0%	20,729
Support Systems	kg	0%	?	5-15%	7,812	14%	6,927
Sub-Total	kg		**?**		**28,540**		**27,656**

2 x Jupiter 232 Architecture Comparison

- Case #1: LOR-LOR -

Direct v2.0							
		2 x Jupiter 232 Stated Performance		2 x Jupiter 232 Assessed Performance (Team A)		2 x Jupiter 232 Assessed Performance (Team B)	
	Units	GR&A (%)		GR&A (%)		GR&A (%)	
Structures Mass							
Primary Body Structures	kg	0%	?	15%	41,291	10%	42,917
Secondary Body Structures	kg	0%	?	15%	3,591	15%	3,483
Sub-Total	kg		**?**		**44,882**		**46,400**
Ancillary Systems Mass							
Separation Systems	kg	0%	?	0%	1,651	0%	1,652
TPS	kg	0%	?	5%	333	5%	332
TCS	kg	0%	?	7%	1,591	8%	2,307
Power (Electrical)	kg	0%	?	14%	1,129	14%	1,251
Power (Hydraulic)	kg	0%	?	15%	551	15%	520
Avionics	kg	0%	?	10%	213	10%	213
Miscellaneous	kg	0%	?	15%	173	15%	223
Sub-Total	kg		**?**		**5,640**		**6,499**
Total Dry Mass Without Growth	kg		**?**		**79,063**		**80,554**
GR&A Dry Mass Allowance	kg		?		7,793		6,322
Total Dry Mass With Growth	kg		**69,582**		**86,856**		**86,876**
Residuals		% Nominal					
Reserves	kg	?	?		1,073		1,073
Residuals	kg	?	?		7,126		7,116
In Flight Losses	kg	?	?		76		72
Sub-Total	kg	?	**6,699**		**8,275**		**8,260**
Total Burnout Mass	kg		**76,281**		**95,131**		**95,137**
Nominal Ascent Propellant	kg		723,515		723,516		724,138
Engine Purge Helium	kg	(27.3 kg/RS-68)	?		74		74
Total Stage Glow	kg		799,796		818,721		819,349
Stage pmf (full)			0.9046		0.8838		0.8839

2 x Jupiter 232 Architecture Comparison

- Case #1: LOR-LOR -

Direct v2.0							
		2 x Jupiter 232 Stated Performance		2 x Jupiter 232 Assessed Performance (Team A)		2 x Jupiter 232 Assessed Performance (Team B)	
	Units	GR&A (%)		GR&A (%)		GR&A (%)	
Upper Stage Specifications							
Number of Engines			2		2		2
J-2			(J-2XD; May 2006)		J-2X		(J-2XD; May 2006*)
Isp (vac)	s		448		448		448
Oxidizer/Fuel Ratio			6		5.5		6
Maximum Thrust			(100% vac)		(100% vac)		(100% vac)
	N		1,217,000		1,307,777		1,217,000
	lb_f		273,500		294,000		273,500
Main Propulsion System Mass							
Sub-Total	kg		**?**		**7,345**		**7,411**
Structures Mass							
Primary Body Structures	kg	0%	?	15%	15,808	11%	17,022
Secondary Structures	kg	0%	?	15%	2,059	15%	2,227
Sub-Total	kg		**?**		**17,867**		**19,249**
Ancillary Systems Mass							
Separation Systems	kg	0%	?	15%	119	15%	122
TPS	kg	0%	?	5%	189	5%	190
TCS	kg	0%	?	7%	830	8%	1,145
Auxiliary Propulsion System	kg	0%	?	15%	176	15%	368
Power (Electrical)	kg	0%	?	14%	766	14%	1,063
Power (Hydraulic)	kg	0%	?	15%	234	15%	235
Avionics	kg	0%	?	10%	195	15%	579
Miscellaneous	kg	0%	?	15%	81	15%	98
Sub-Total	kg		**?**		**2,590**		**3,798**

2 x Jupiter 232 Architecture Comparison

- Case #1: LOR-LOR -

Direct v2.0							
		2 x Jupiter 232 Stated Performance		2 x Jupiter 232 Assessed Performance (Team A)		2 x Jupiter 232 Assessed Performance (Team B)	
	Units	GR&A (%)		GR&A (%)		GR&A (%)	
Total Dry Mass Without Growth	kg		**?**		**27,802**		**30,458**
GR&A Dry Mass Allowance	kg		?		3,138		2,803
Total Dry Mass With Growth	kg		**20,343**		**30,941**		**33,261**
Residuals							
Reserves	kg		?		2,089		2,424
Residuals	kg		?		3,020		4,163
In Flight Losses	kg		?		39		896
Sub-Total	kg		**2,719**		**5,148**		**7,483**
Total Burnout Mass	kg		**23,062**		**36,089**		**40,744**
Usable Ascent Propellant Mass (suborbital)	kg	Figure 10	241,590		241,590	From	241,590
Usable TLI Propellant Mass	kg		108,100		60,678		66,406
Usable LOI Propellant Mass	kg		?		16,780		16,012
Engine Purge Helium Mass	kg		?		36		36
RCS Propellant (ascent)	N/A	N/A	N/A		272		939
Payload Adapter/Tank Interface	kg				0		0
Total Stage GLOW	kg		372,752		355,445		365,727
Stage pmf (full)			0.9129		0.8976		0.8859

Jupiter 120 - 232 Architecture Comparison

- Case #2: EOR-LOR -

Direct v2.0							
		Jupiter 120 plus Jupiter 232 Stated Performance		Jupiter 120 plus Jupiter 232 Assessed Performance (Team A)		Jupiter 120 plus Jupiter 232 Assessed Performance (Team B)	
	Units	GR&A (%)		GR&A (%)		GR&A (%)	
GLOW (total)	kg		2,371,593		2,374,578		2,371,124
CEV Rendezvous Mass	kg		25,000		20,200		25,000
Lander Mass (+ adapter, etc.)	kg		38,000 - 45,000		15,570		12,900
Total TLI delivery mass	**kg**		**63,000 - 70,000**		**35,770**		**37,900**
Booster Stage Specifications							
# Boosters (total)			2		2		2
Booster Prop (each)	kg		501,467		504,215		504,230
Booster mbo (each)	kg		87,604		84,760		85,250
Booster Thrust (vac @ <= 1sec)	N		14,823,714		13,865,130		13,982,585
Booster Thrust (vac @ <= 1sec)	lbf		3,331,400		3,117,005		3,142,302
Booster Isp (vac @ <= 1 sec)	s		268.0		266.9		269.1
Core Stage Specifications							
Number of Engines			3		3		3
RS-68			(existing ablative)		(ablative)		(ablative)
Isp (SL)	s		357.0		356.1		356.7
Isp (vac)	s		409.0		409.0		409.5
Maximum Thrust			(100% SL)		(102% SL)		(100% SL)
	N		2,919,000		2,919,000		2,867,000
	lb_f		656,000		656,000		644,300
Maximum Thrust			(100% vac)		(102% Vac)		(100% vac)
	N		3,341,000		3,341,000		3,292,000
	lb_f		751,000		751,000		740,000
Main Propulsion System Mass							
Total Engine	kg	0%	?		20,729	0%	20,729
Support Systems	kg	0%	?		7,501	14%	6,959
Sub-Total	kg		**?**		**28,230**		**27,688**

Jupiter 120 - 232 Architecture Comparison

- Case #2: EOR-LOR -

Direct v2.0							
		Jupiter 120 plus Jupiter 232 Stated Performance		Jupiter 120 plus Jupiter 232 Assessed Performance (Team A)		Jupiter 120 plus Jupiter 232 Assessed Performance (Team B)	
	Units	GR&A (%)		GR&A (%)		GR&A (%)	
Structures Mass							
Primary Body Structures	kg	0%	?	10%	42,836	10%	43,386
Secondary Body Structures	kg	0%	?	15%	3,663	15%	3,507
Sub-Total	kg		**?**		**46,499**		**46,893**
Ancillary Systems Mass							
Separation Systems	kg	0%	?	0%	1,648	0%	1,655
TPS	kg	0%	?	5%	331	5%	332
TCS	kg	0%	?	7%	1,591	8%	2,307
Power (Electrical)	kg	0%	?	14%	1,129	14%	1,251
Power (Hydraulic)	kg	0%	?	15%	528	15%	520
Avionics	kg	0%	?	10%	213	10%	213
Miscellaneous	kg	0%	?	15%	173	15%	223
Sub-Total	kg		**?**		**5,612**		**6,502**
Total Dry Mass Without Growth	kg		**?**		**80,341**		**81,082**
GR&A Dry Mass Allowance	kg				6,031		6,377
Total Dry Mass With Growth	kg		**69,582**		**86,372**		**87,459**
Residuals		% Nominal					
Reserves	kg	?	?		1,072		1,073
Residuals	kg	?	?		7,126		7,115
In Flight Losses	kg	?	?		73		72
Sub-Total	kg	?	**6,699**		**8,272**		**8,260**
Total Burnout Mass	kg		**76,281**		**94,643**		**95,719**
Nominal Ascent Propellant	kg		723,515		723,516		724,138
Engine Purge Helium	kg	(27.3 kg/RS-68)	?		74		74
Total Stage Glow	kg		799,796		818,234		819,931
Stage pmf (full)			0.9046		0.8843		0.8832

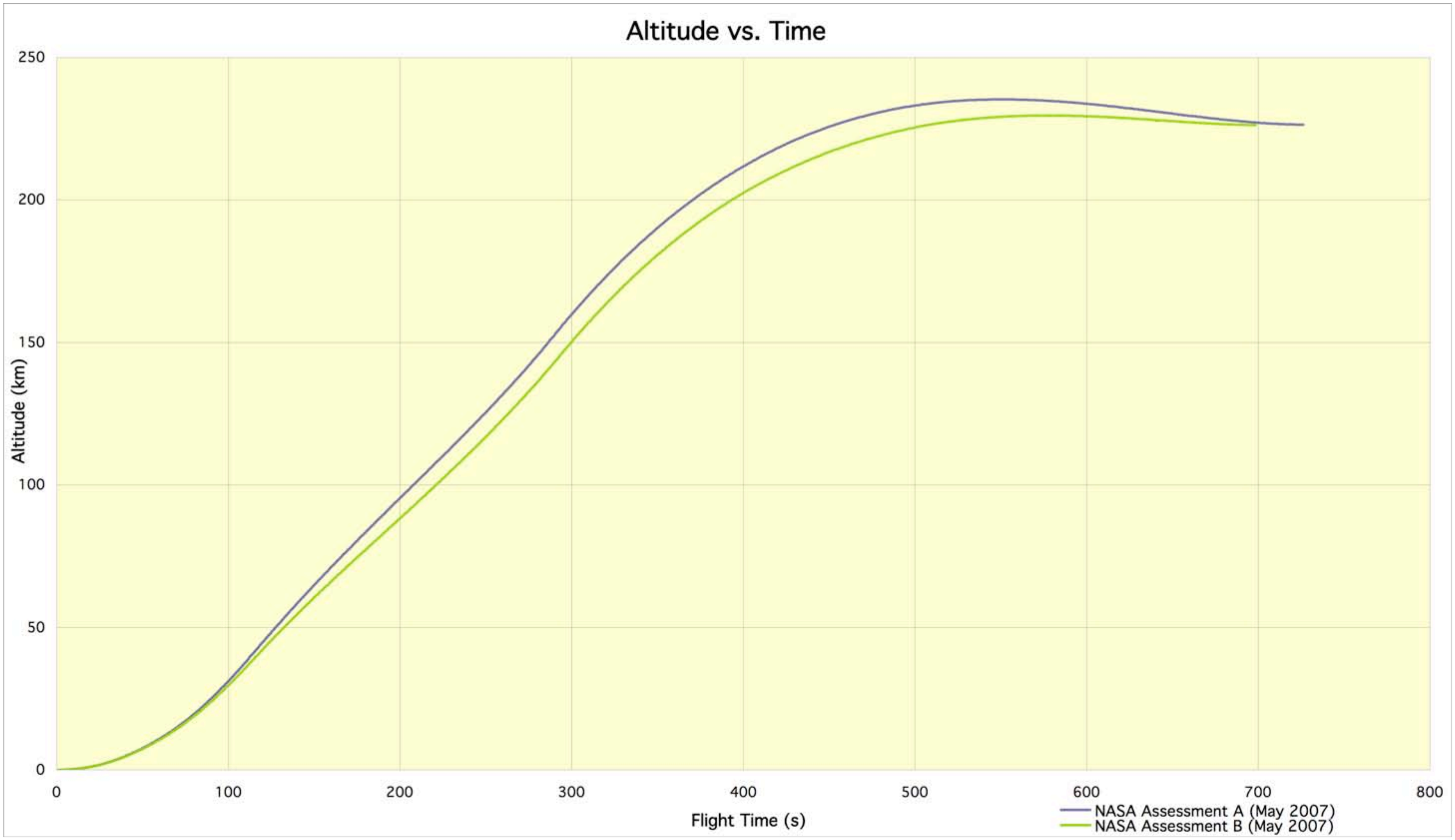
Jupiter 120 - 232 Architecture Comparison
- Case #2: EOR-LOR -

Direct v2.0							
		Jupiter 120 plus Jupiter 232 Stated Performance		Jupiter 120 plus Jupiter 232 Assessed Performance (Team A)		Jupiter 120 plus Jupiter 232 Assessed Performance (Team B)	
	Units	GR&A (%)		GR&A (%)		GR&A (%)	
Upper Stage Specifications							
Number of Engines			2		2		2
J-2			(J-2XD; May 2006)		J-2X		(J-2XD; May 2006*)
Isp (vac)	s		448		448		448
Oxidizer/Fuel Ratio			6		5.5		6
Maximum Thrust			(100% vac)		(100% vac)		(100% vac)
	N		1,217,000		1,217,000		1,217,000
	lb_f		273,500		273,500		273,500
Main Propulsion System Mass							
Sub-Total	kg		**?**		**7,237**		**7,411**
Structures Mass							
Primary Body Structures	kg	0%	?	11%	17,338	11%	17,022
Secondary Structures	kg	0%	?	15%	2,254	15%	2,227
Sub-Total	kg		**?**		**19,592**		**19,249**
Ancillary Systems Mass							
Separation Systems	kg	0%	?	15%	132	15%	120
TPS	kg	0%	?	5%	189	5%	190
TCS	kg	0%	?	7%	746	8%	1,145
Auxiliary Propulsion System	kg	0%	?	15%	366	15%	373
Power (Electrical)	kg	0%	?	14%	910	14%	1,063
Power (Hydraulic)	kg	0%	?	15%	219	15%	235
Avionics	kg	0%	?	15%	579	15%	579
Miscellaneous	kg	0%	?	15%	71	15%	98
Sub-Total	kg		**?**		**3,211**		**3,802**

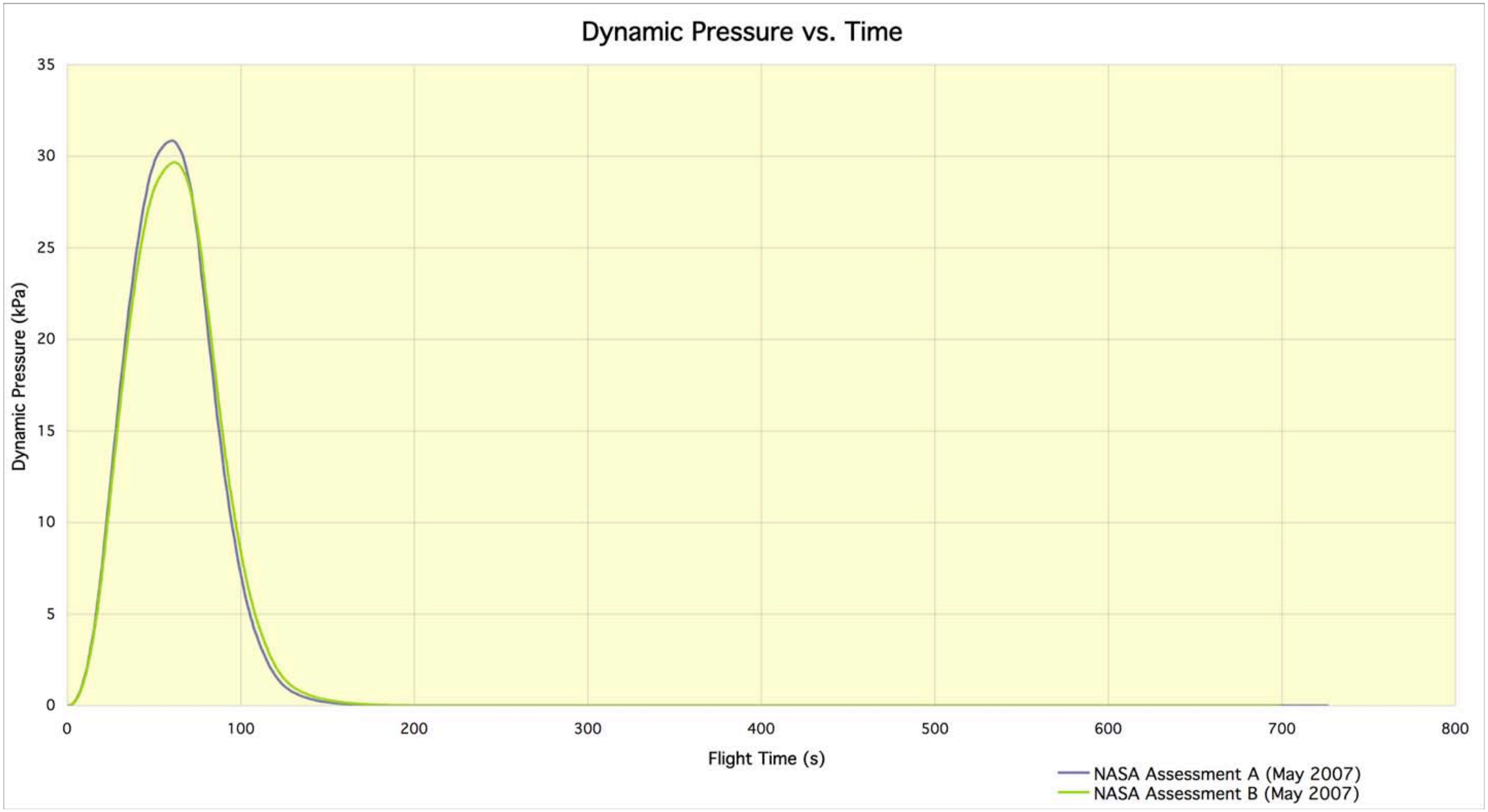
Jupiter 120 - 232 Architecture Comparison
- Case #2: EOR-LOR -

Direct v2.0							
		Jupiter 120 plus Jupiter 232 Stated Performance		Jupiter 120 plus Jupiter 232 Assessed Performance (Team A)		Jupiter 120 plus Jupiter 232 Assessed Performance (Team B)	
	Units	GR&A (%)		GR&A (%)		GR&A (%)	
Total Dry Mass Without Growth	kg		**?**		**30,040**		**30,461**
GR&A Dry Mass Allowance	kg				2,811		2,803
Total Dry Mass With Growth	kg		**20,343**		**32,851**		**33,265**
Residuals							
Reserves	kg		?		1,898		2,621
Residuals	kg		?		4,417		4,120
In Flight Losses	kg		?		943		853
Sub-Total	kg		**2,719**		**7,259**		**7,594**
Total Burnout Mass	kg		**23,062**		**40,110**		**40,859**
Usable Ascent Propellant Mass (suborbital)	kg	Figure 10	241,590		241,590	From	241,590
Usable TLI Propellant Mass	kg		108,100		73,966		76,067
Engine Purge Helium Mass	kg		?		40		36
RCS Propellant (ascent)	N/A	N/A	N/A		939		939
Payload Adapter/Tank Interface	kg				0		0
Total Stage GLOW	kg		372,752		356,655		359,492
Stage pmf (full)			0.9129		0.8848		0.8836

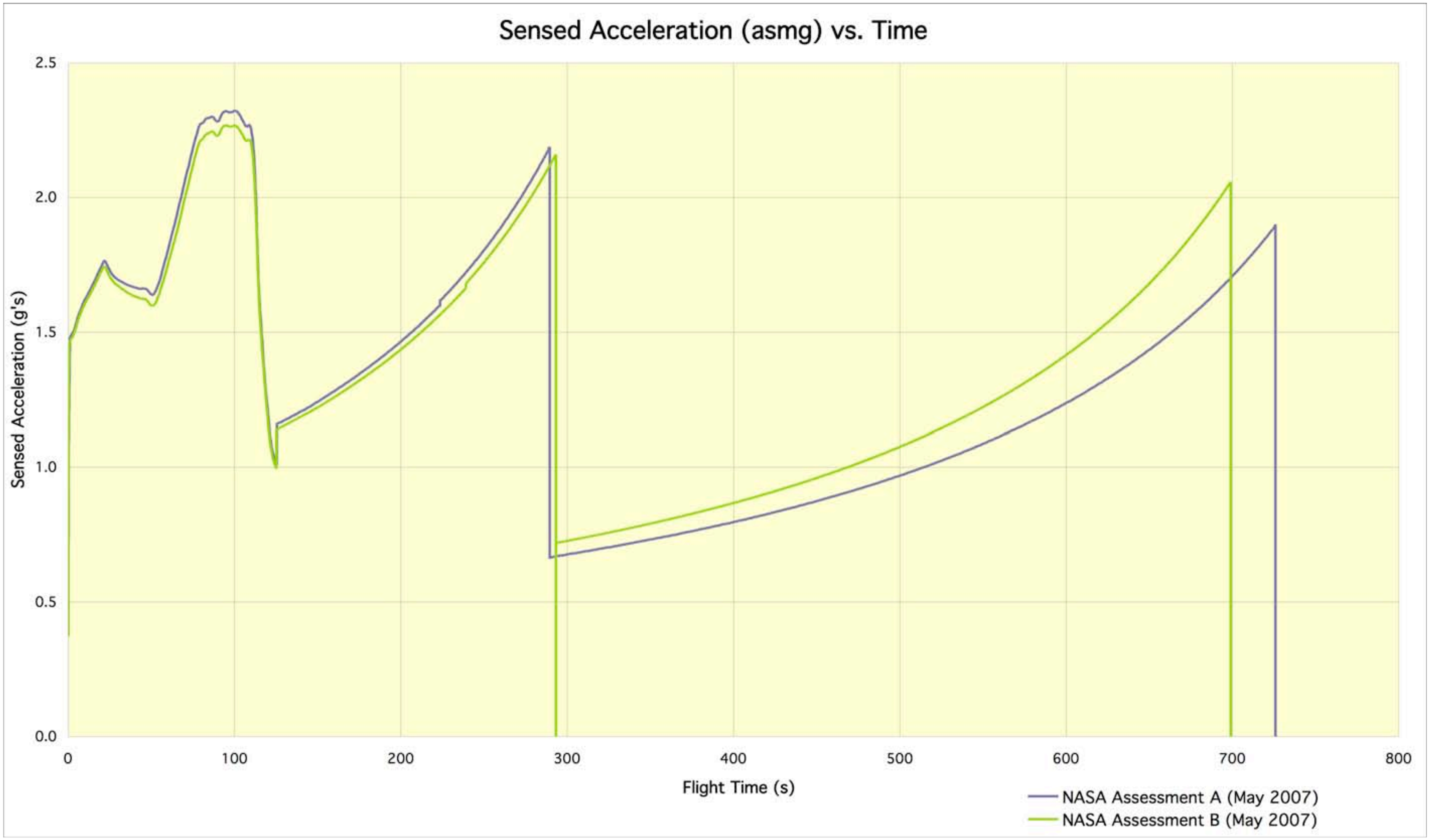
37.03.03
(EOR-LOR) Altitude vs Time



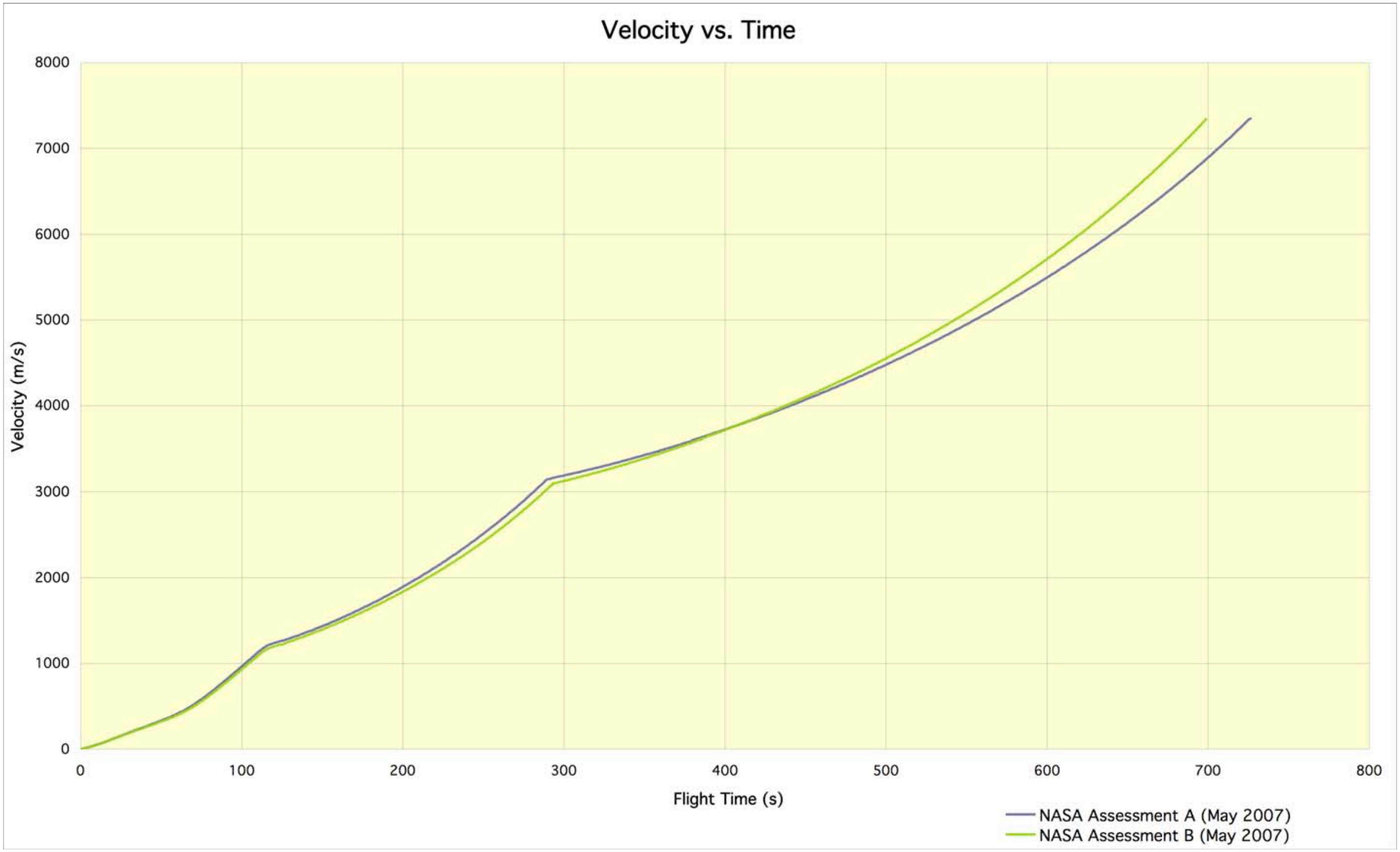
37.03.03 (EOR-LOR) Dynamic Pressure vs Time



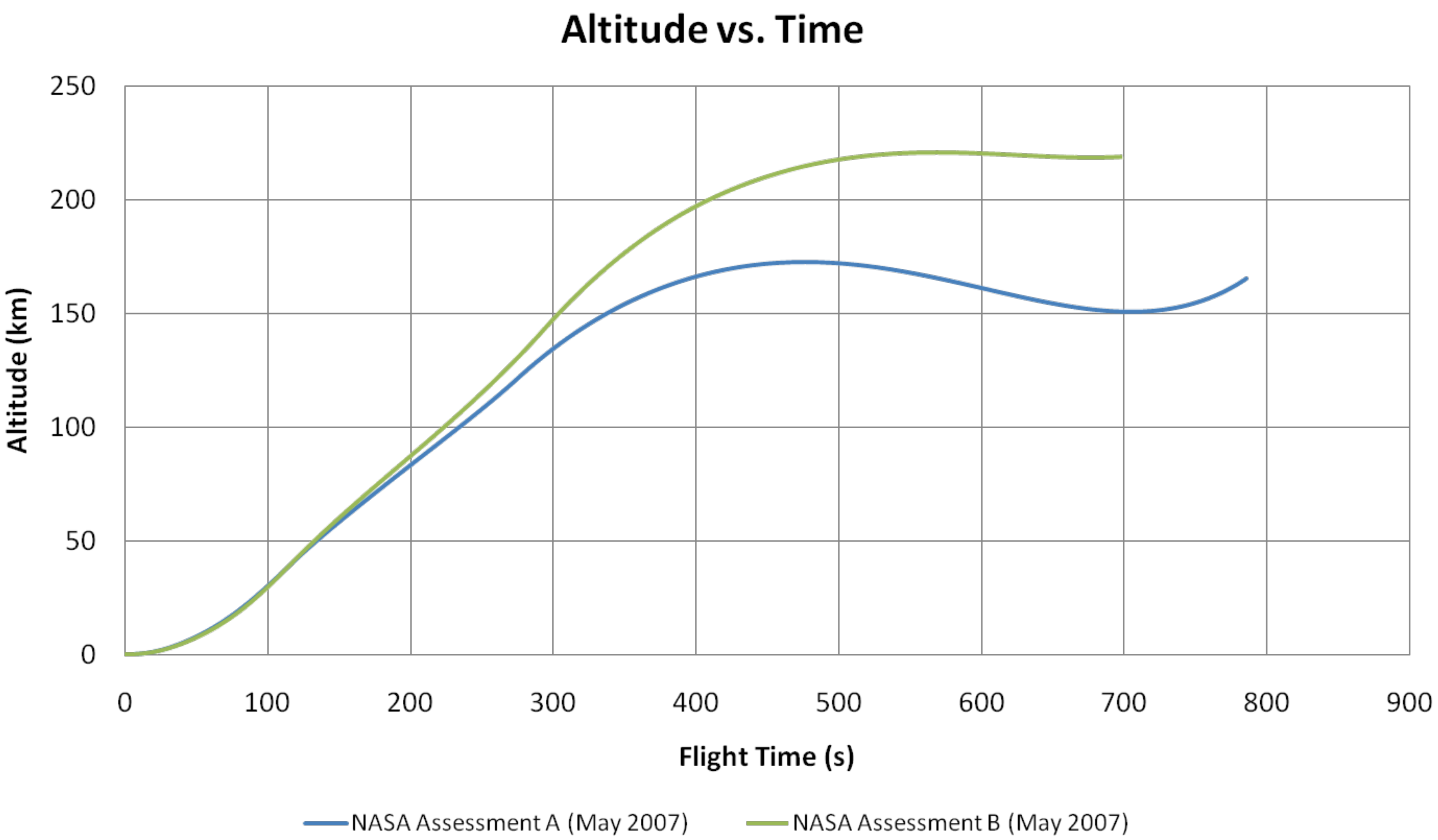
37.03.03 (EOR-LOR) Acceleration vs Time



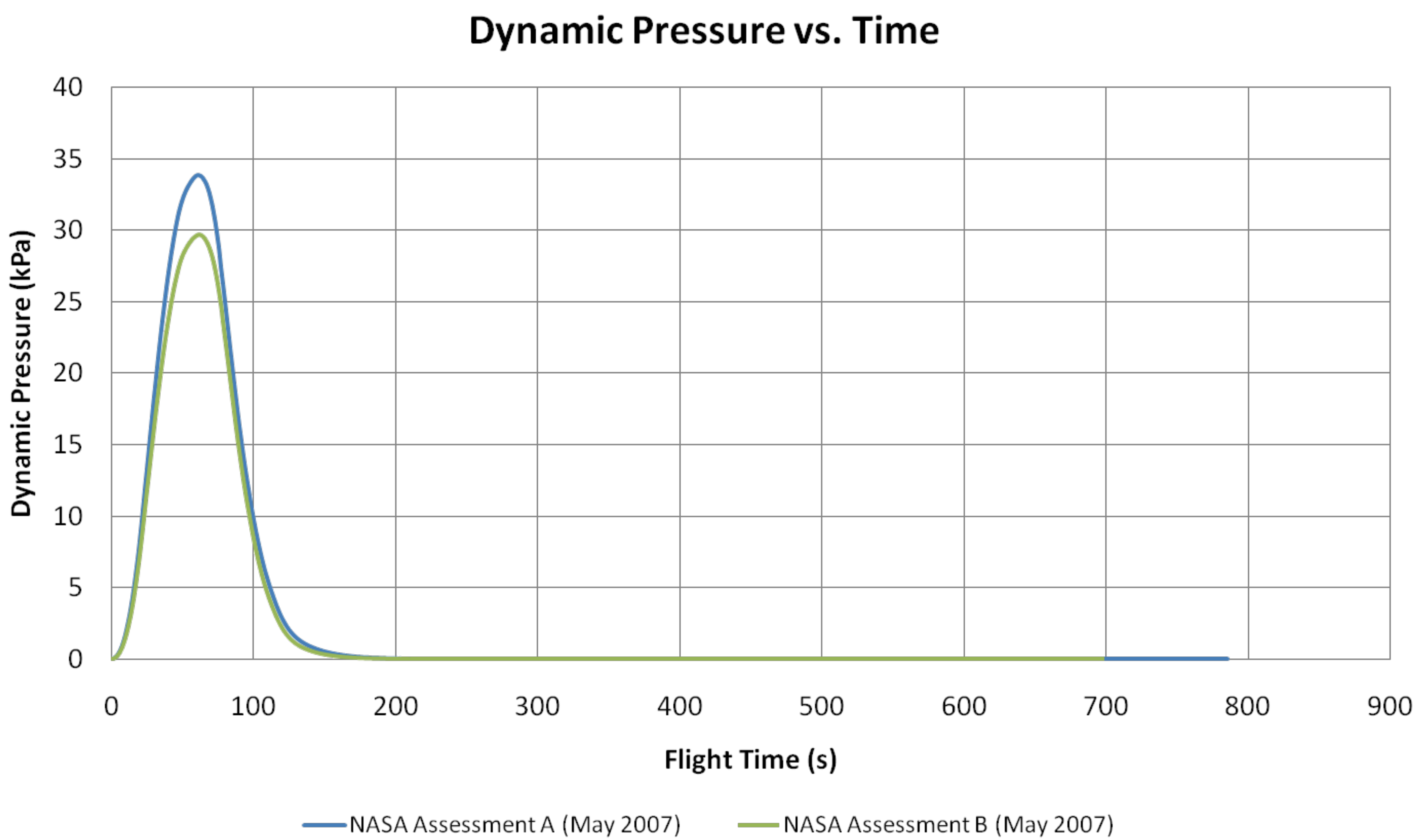
37.03.03 (EOR-LOR) Velocity vs Time



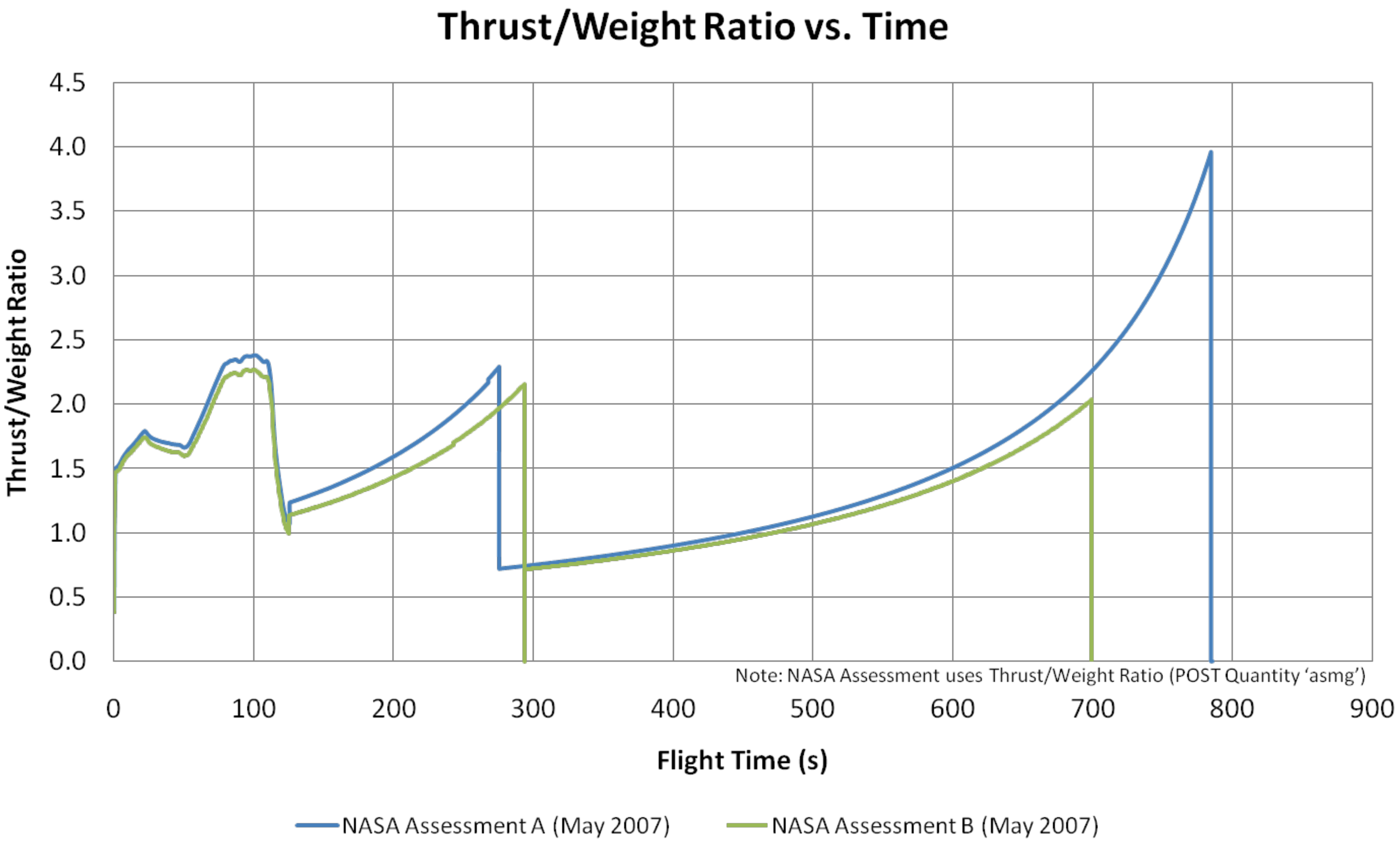
May 2007 Performance Assessment (LOR-LOR)



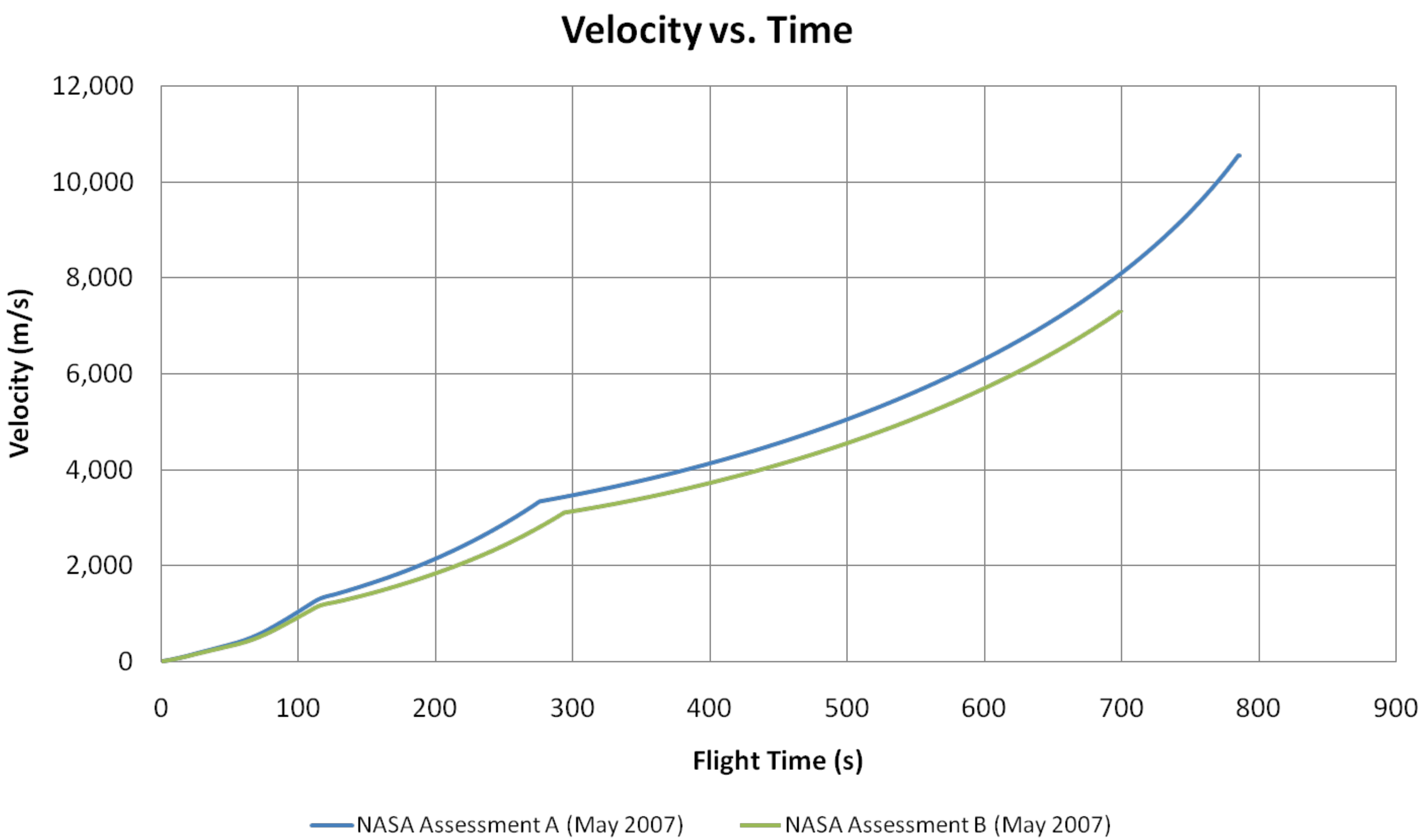
May 2007 Performance Assessment (LOR-LOR)



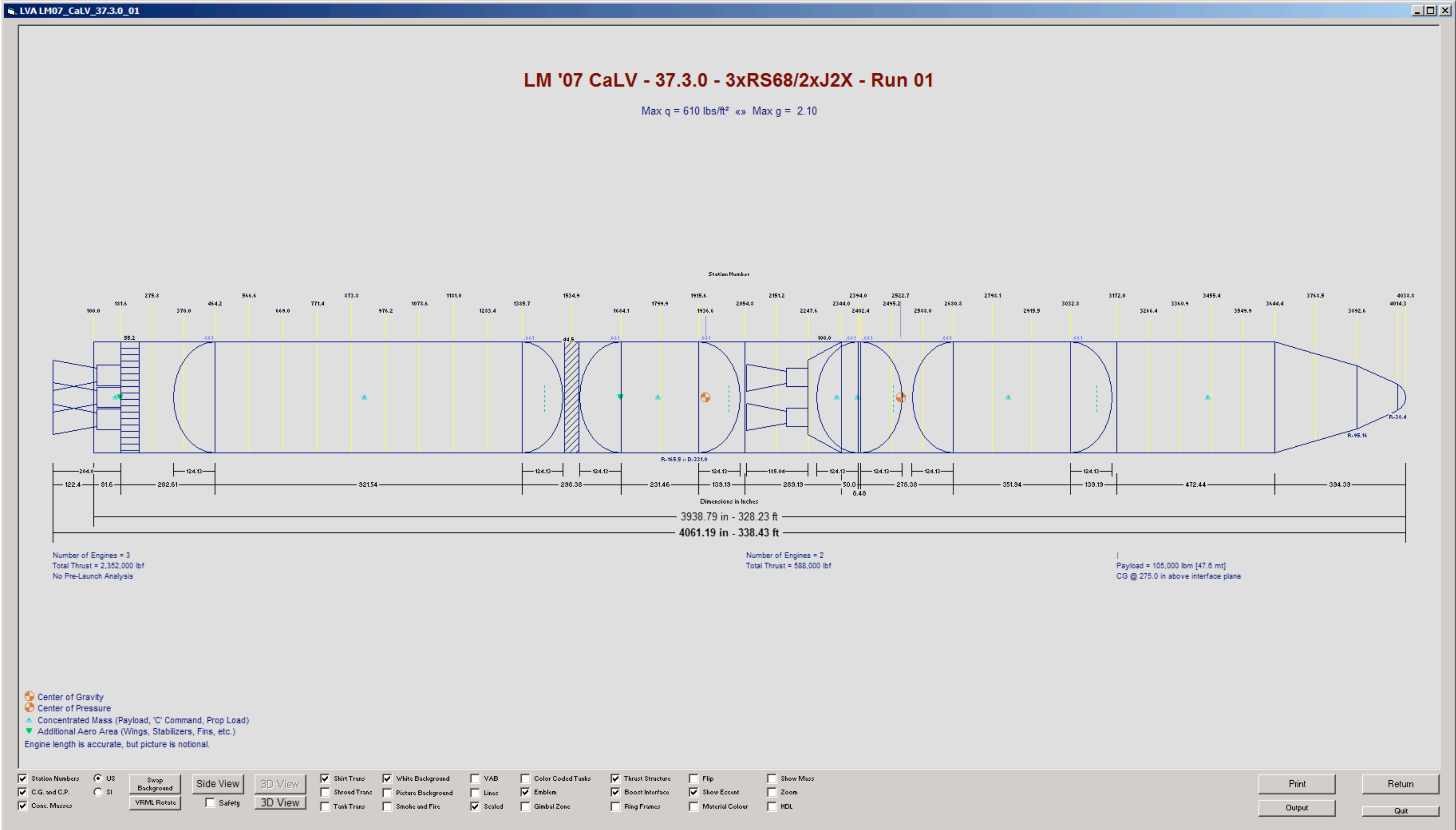
May 2007 Performance Assessment (LOR-LOR)



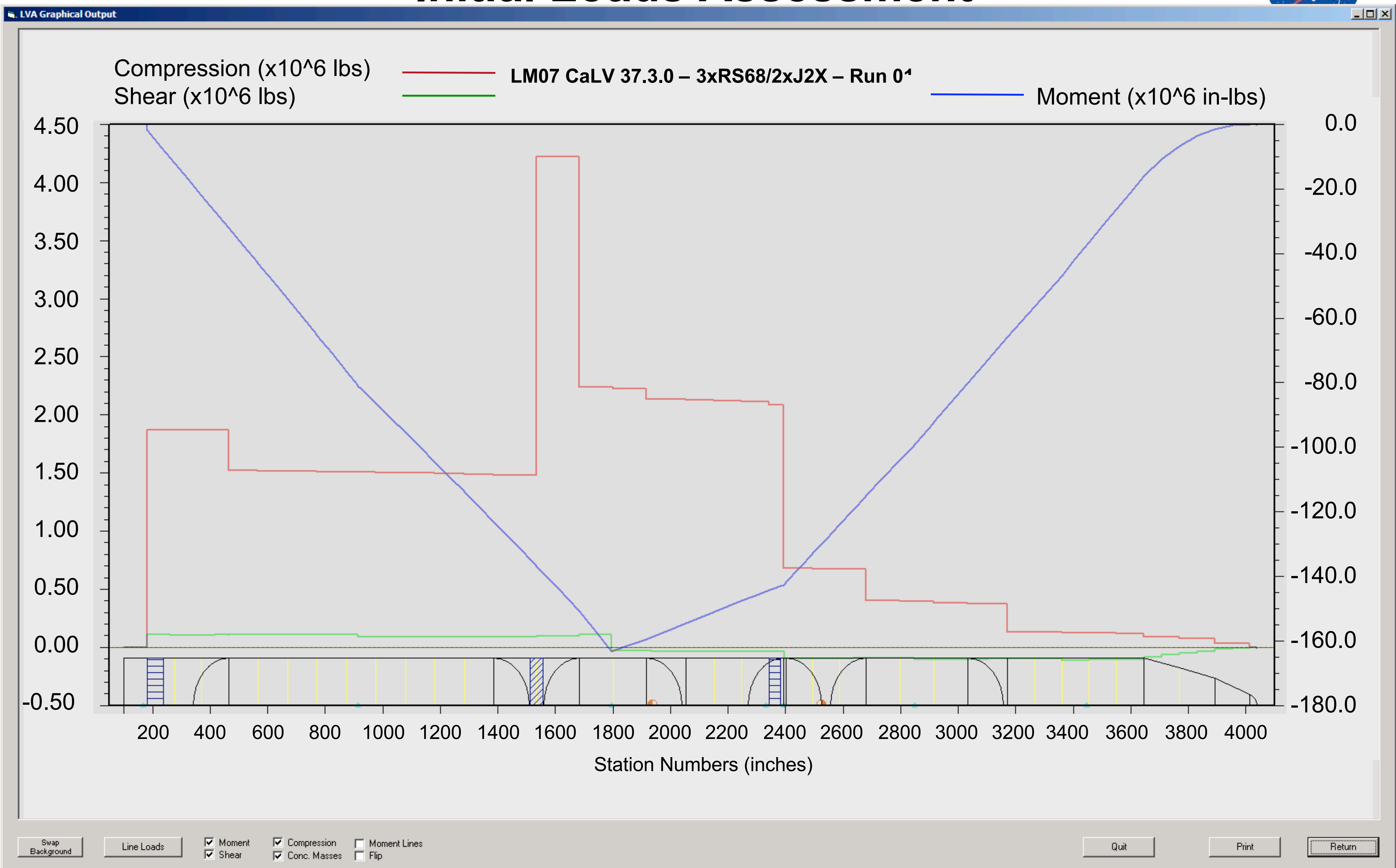
May 2007 Performance Assessment (LOR-LOR)

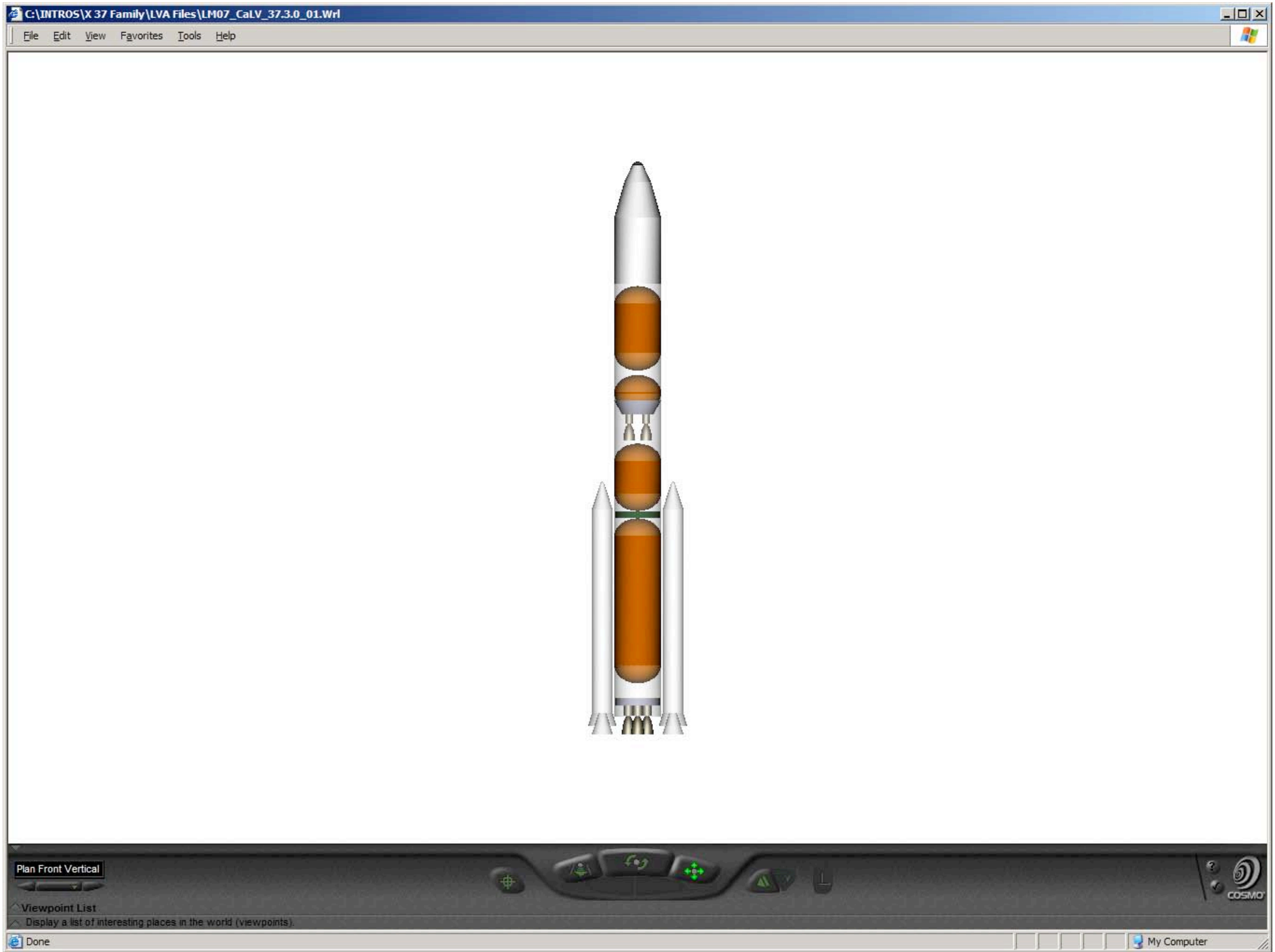


Config for Loads Assessment



Initial Loads Assessment

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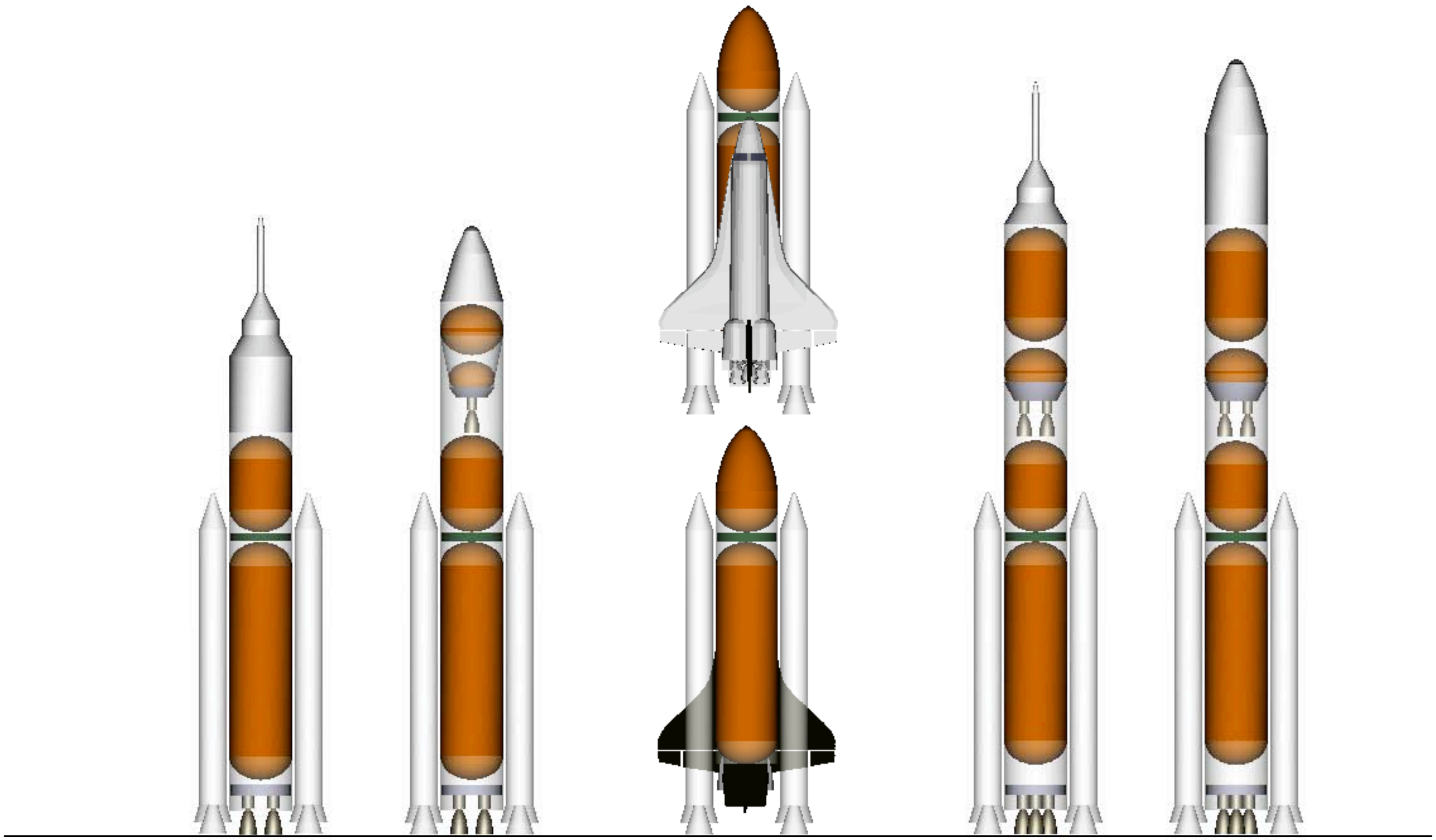
Plan Front Vertical
Viewpoint List
Display a list of interesting places in the world (viewpoints).
COSMO
Done
My Computer



Jupiter 120 Crewed

Jupiter 120 Cargo

STS

Jupiter 232 Crewed

Jupiter 232 Cargo

Acronyms

AIAA	American Institute of Aeronautics and Astronautics
BPC	Boost Protective Cover
CARD	Constellation Architecture Requirements Document
CDR	Critical Design Review
CEV	Crew Exploration Vehicle
CFM	Cryogenic Fluid Management
EDS	Earth Departure Stage
EML1	Earth-Moon Lagrange Point 1
EOR-LOR	Earth Orbit Rendezvous-Lunar Orbit Rendezvous
ESAS	Exploration Systems Architecture Study
ET	External Tank
FPR	Flight Performance Reserve
GLOW	Gross Lift Off Weight
GR&A	Ground Rules & Assumptions
HLR	Human Lunar Return
IDAC	Integrated Design Analysis Cycle
INTROS	Integrated Rocket Sizer
IVGVT	Integrated Vehicle Ground Vibration Test
KSC	Kennedy Space Center
LAS	Launch Abort System
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LOI	Lunar Orbit Insertion
LOR-LOR	Lunar Orbit Rendezvous-Lunar Orbit Rendezvous
LOX	Liquid Oxygen
LSAM	Lunar Surface Access Module
LVA	Launch Vehicle Analyzer
MBO	Mass at Burn Out
MECO	Main Engine Cut Off
MMOD	Micro Meteroid and Orbital Debris
NASA	National Aeronautics and Space Administration
PBAN	Polybutadiene Acrylonitrile

Acronyms

PMF	Propellant Mass Fraction
PLOC	Probability of Loss of Crew
PLOM	Probability of Loss of Mission
PDR	Preliminary Design Review
POST	Program to Optimize Simulated Trajectories
RSRB	Reusable Solid Rocket Booster
SDR	System Design Review
SIL	Systems Integration Lab
SLA	Spacecraft Launch vehicle Adapter
SRB	Solid Rocket Booster
SRR	System Requirements Review
STS	Space Transportation System
T/W	Thrust-to-Weight ratio
TLI	Trans Lunar Injection
TCS	Thermal Control System
TPS	Thermal Protection System
VAB	Vehicle Assembly Building